BULLETIN
of the
American Association *of* Petroleum Geologists

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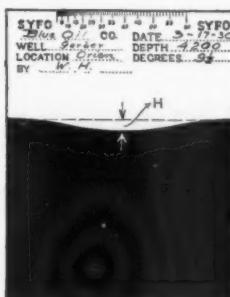
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of the

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REVIEW OF GEOPHYSICAL PROSPECTING FOR PETROLEUM, 1929[1]

DONALD C. BARTON[2]

Houston, Texas

ABSTRACT

The campaign of geophysical exploration continued without abatement in the Gulf Coast region during 1929. Thirty-five prospective salt domes were discovered during the year. Six commercial oil fields were discovered in the Gulf Coast region and one, Van, in northeast Texas, on geophysically discovered salt domes or structure. The torsion balance was restored to favor for reconnaissance for (deep) salt domes, and by the end of the year, about eighty torsion balances were working in the Gulf Coast region. In the United States, outside of the Gulf Coast salt-dome area, the seismic torsion-balance methods, to a less extent the magnetometer, and to a very much less extent the electric method, continued in moderate or sporadic use in Texas, Louisiana, Mississippi, Arkansas, Oklahoma, Kansas, Colorado, New Mexico, California, and Michigan. In foreign countries, considerable use of geophysical methods continued in Mexico, Venezuela, and Roumania, and there was some use of them in many other countries.

Opinion among geologists is divided in regard to the value of geophysics in the non-salt-dome areas. All of the four main methods have demonstrated some ability to map structure, but each is being charged with many seeming failures. The evaluation of the true significance of these failures and of the final places of the several geophysical methods will not be possible until more geologic data are available. As development of the use of geophysics in the Gulf Coast region has reached a much higher stage than elsewhere, the history of geophysical methods in that region affords a lesson of what possibly we should expect else-

[1] Read before the Association at the New Orleans meeting, March 21, 1930.

[2] Consulting geologist and geophysicist.

where. The history of the torsion balance in the Gulf Coast region is divisible into three eras. In the first era, the torsion balance was used to map known domes and then to search for maxima similar to those which had been mapped on the known domes; four salt domes were discovered. In the second era, on account of the entirely negative results of tests on three large minima and on several non-typical maxima, the torsion balance was almost entirely discredited for reconnaissance for salt domes. In the third era, the high value of those minima as indications of deep domes became evident and the torsion balance came back into extensive use in reconnaissance for deep domes. The seismic method also has gone through three periods. In the first period, the time of explosion was determined by the air-wave method, and the effective working depth of the method did not extend below 2,500 feet. In the second period, the time of the shot was transmitted by wireless and the effective working depth of the method was 4,500 feet. In the third period, the torsion-balance discoveries of very deep domes forced the seismic method to increase its effective depth range to 7,500 feet. A fourth period seems now to be beginning and to be marked by the decline of the refraction method and by the increasing importance of the reflection method.

The following lessons are suggested by the history of the methods in the Gulf Coast region and are applicable elsewhere: (1) much condemnation of the methods is too hasty; (2) many entirely negative tests on geophysical prospects are due to only a 25 per cent failure of the method; (3) a method may give a definite indication of the presence of a structure, but may give a very indefinite indication of the position of the crest; (4) the personal equation of the interpreter enters into the success of the methods; (5) many of the tests which have been entirely negative have been drilled on border-line prospects; (6) the accuracy of interpretation grows with the growth of the geological-geophysical knowledge of an area; (7) one method may be valuable for one purpose, another for another; (8) geophysical interpretation and some geophysical work may be obsolete; (9) regional surveys are of value not only in expediting the development of interpretation but in giving a considerable advantage over competitors when the significance of anomalies becomes evident. In conclusion, the writer expresses three thoughts: (1) that the many definite anomalies, which have been mapped in many places and which at present are not definitely interpretable, indicate geologic features, and that some of them presently will be of significance to the petroleum geologist when they are properly interpreted; (2) that although geophysics

is a valuable tool for the petroleum geologist, it is no easy means for the discovery of structure or oil; and (3) that there is great danger in amateur interpretation — isogams show the variation of a physical effect and are not easily convertible into structure contours.

In the Gulf Coast region during 1929, the seismic and torsion-balance methods maintained their eventful successes of previous years. Through drilling on domes discovered by those methods, more oil fields were discovered during the year than in any previous year in the history of this region. The geological power of both methods developed so that during the year they have been used at much greater depths than in previous years. The Gulf Coast region is now being re-shot for the third and fourth consecutive times.

Many salt domes were discovered by the seismic and torsion-balance methods in the Gulf Coast region during 1929. A tentative list of these discoveries, and of the prospective domes which as yet have not been confirmed by drilling, is given in Table I. It is difficult to get authentic information about many prospects, particularly about border-line prospects.

In contrast to the rather definite seismic anomalies which were sought in 1927 and 1928, more attention was paid in 1929 to the less definite seismic and torsion-balance anomalies, which indicate the deep and very deep salt domes. More work is necessary to check border-line anomalies possibly indicating deep domes, and the competing companies do not attempt to check all reported discoveries of domes. With all the data on a prospect, it may be difficult to conclude whether a deep dome "probably is present" or whether a deep dome "possibly is, but probably is not, present." The further data about a new dome may be known only to the discovering company. All of the prospective domes are supposed to be deep or very deep domes. Some of them may not affect beds within reach of the drill. Some of them are on the border line of probability and will prove not to be domes. The discovery of some of the domes probably should be credited to 1928. The presence of the salt at Danbury has been confirmed by drilling and the establishment of production at Hankamer and Pala Blanca indirectly confirms the presence of domes at those prospects.

More oil fields were discovered in 1929 than in any previous year during the history of the Gulf Coast region, and, with the exception of Clay Creek, all of the fields were on domes which had been discovered

TABLE I

DOMES AND PROSPECTIVE DOMES[1] DISCOVERED DURING 1929[2] IN GULF COAST REGION

Dome	County or Parish[3]	Discovered by	Method Used	Dome[4] Confirmed by Drilling	Production Established	Drilled
Austin Bayou	Brazoria Co.	Rycade Oil Co.	Seismic	....		Dr.
Barataria	Jefferson Pa.	....	Seismic			Dr.
Bayou Chene	St. Martin Pa.	The Texas Co.	Seismic			No
Beasley	Ft. Bend Co.	Humble Oil and Refining Co.	T. B.	....		1 well
Cameron Meadows	Cameron Pa.	Vacuum Oil Co.	Seismic			Dr.
Carencro	St. Landry Pa.	The Pure Oil Co.	Seismic			No
Cedar Bayou	Harris Co.	Shell Petroleum Corp. Sloan Prospecting Co.	Seismic T. B.			2 wells
Cheek	Jefferson Co.	H. C. Cockburn	T. B.			No
Clodine	Ft. Bend Co.	Meyer & Sorelle	T. B.			2 wells
Cove	Chambers Co.	The Pure Oil Co.	Seismic	Discredited		1 well
Danbury	Brazoria Co.	Shell Petroleum Corp.	Seismic	Yes	....	1 well
Devers	Liberty Co.	Humble Oil and Refining Co.	T. B.		....	1 well
East Stratton Ridge	Brazoria Co.	Rycade Oil Corp.	Seismic			Dr.
Eureka	Harris Co.	Humble Oil and Refining Co. Navarro Oil Co.	T. B.	....		1 well
Fairbanks	Harris Co.	Petty Petroleum Corp.	Seismic			No
Golden Meadow	La Fourche Pa.	Humble Oil and Refining Co.	Seismic			No
Gueydan	Vermillion Pa.	The Pure Oil Co.	Seismic			No
Hankamer	Liberty Co.	Gulf Production Co.	T. B.	Yes	Yes	Yes
Hayes	Calcasieu Pa. and Jefferson Davis Pa.	Gulf Production Co. Humble Oil and Refining Co.	T. B. T. B.	....		Yes
Iota	Acadia Pa.	....	Seismic & T. B.			No
Iowa	Calcasieu Pa. and Jefferson Davis Pa.	....	Seismic & T. B.	....		No
Lacasine Bayou	Jefferson Davis Pa.	The Pure Oil Co.	Seismic	Discredited	....	1 well
Manvel	Brazoria Co.	The Texas Co.	....			Dr.
Oyster Bayou High	Chambers Co.	Rycade Oil Co.	Seismic			Dr.
Pala Blanca	Brooks Co.	Shell Petroleum Corp.	Seismic	Yes	Yes	Yes
Point au Fer	Terrebonne Pa.	Freeport Sulphur Co.	Seismic	....		1 well
Rosenburg	Ft. Bend Co.	Humble Oil and Refining Co.	T. B.	....		No
Sargent	Matagorda Co.	Humble Oil and Refining Co. Shell Petroleum Corp.	T. B.	....		No
Satsuma	Harris Co.	Cranfill & Reynolds Oil Co.	T. B.			1 well
St. Martinsville	St. Martin Pa.	Evangeline Oil Co.	T. B.			1 well
Texla	Newton Co.	Gulf Production Co.	T. B.			No
Wax Lake	St. Mary Pa.	The Pure Oil Co.	Seismic	Discredited	....	1 well
Winnie	Jefferson Co.	Cranfill & Reynolds Oil Co.	T. B.			No

[1] Reported prospects known to be dubious are omitted, but reliable evidence in regard to many of the prospective domes listed is not available.

[2] The discoveries are known to have been made or were first reported during 1929.

[3] County in Texas; parish in Louisiana.

[4] Confirmation by drilling into cap rock or salt, or on very deep domes by the discovery of a commercial oil field.

by the use of either the torsion balance or seismograph. The list of those oil fields is given in Table II.

The Van oil field is of the first class. The rank of the other fields has not been established.

The search for deep and very deep domes was an outstanding feature of the year and represents the result of a considerable advance in both the torsion-balance and seismic methods and marks a notable relative gain of the former over the latter. Although first in the field

TABLE II

OIL FIELDS DISCOVERED DURING 1929 ON GEOPHYSICALLY DISCOVERED SALT DOMES OR SALT STRUCTURES

Dome	County or Parish	Discovered by	Discovery Method
Port Barre	St. Landry Pa.	The Texas Co.	Seismic
Hankamer	Liberty Co.	Gulf Prod. Co.	Torsion balance
Esperson	Liberty Co.	Harvey Smith	Torsion balance
Lake Pelto	Terrebonne Pa.	The Texas Co.	Seismic
Caillou Island	Terrebonne Pa.	The Texas Co.	Seismic
Port Neches	Orange Co.	The Texas Co.	Seismic
Van[1]	Van Zant Co.	The Pure Oil Co.	Seismic
Pala Blanca	Brooks Co.	Houston Oil Co.	Seismic
NON-COMMERCIAL WELLS ONLY			
Dog Lake	Terrebonne Pa.	The Texas Co.	Seismic
Genoa[2]	Harris Co.	Humble Oil and Refining Co.	Torsion balance
Mykawa[3]	Harris Co.	Humble Oil and Refining Co.	Torsion balance
Roanoke	Jefferson Davis Co.	Vacuum Oil Co.	Torsion balance
Danbury	Brazoria Co.	Shell Petrol. Corp.	Seismic
Black Bayou	Cameron Pa.	Shell Petrol. Corp.	Seismic
Bayou Bleu	Iberville Pa.	Standard Oil of La.	Seismic

[1]An anticline in northeast Texas salt basin. The presence of salt has not yet been established. Theoretically, it seems probably to be a deep salt ridge.

[2]Gas only.

[3]Gas and a little oil.

and first to discover salt domes, the torsion-balance method was almost completely displaced by the seismic method for reconnaissance on account of the equal ability, much greater speed, and lower costs per acre of the seismic method in the search for domes within 4,000 feet of the surface. The discovery of the Dewalt salt dome in 1928 by the torsion balance in a much shot-over area led to a more general appreciation of the significance of such large gravity minima and the value of torsion balance in the search for deep domes. On two other such minima, Es-

person and Hankamer, which were rather generally condemned by the seismic method and which were rated by Gulf Coast geologists as rather low-grade prospects, commercial wells were completed during 1929. By the last half of the year more than eighty torsion balances were operating in the Gulf Coast region. Simultaneously with the growing appreciation of the significance and importance of the gravity minima, certain faint indications obtained by the seismic method have come to be recognized as significant. Esperson, Hankamer, and Port Neches gave faint seismic irregularities which were neither as large nor as definite as those known to be associated with salt domes and which geologically, therefore, originally were unimportant. The Texas Company finally drilled one of these low-grade seismic prospects, Port Neches, during the year, and completed a commercial oil well. These fainter seismograph irregularities are now being more carefully investigated and by combination of torsion-balance and seismic surveys many of them now are understood to represent deep salt domes in which the salt lies below the reach of the refraction (seismic) method. With the increasing emphasis of prospecting during 1929 on deep salt domes, the seismic method has increased its effective depth range from 5,000-6,000 feet to 7,000-8,000 feet. Although the torsion-balance method has a certain superiority in the detection of the presence of deep salt domes, an inherent indefiniteness exists in its indication of the position of the crest of the dome; the seismic method may have to be used to contour some seismic horizon in the super-salt beds.

The Gulf Coast salt-dome area is now in process of the third and fourth re-shooting. In the first period, 1924-1926, the maximum shot-to-receiver distance was 2½ miles; consequently, the effective maximum depth range was about 3,000 feet; most of the work was done by Seismos, using the inaccurate and now obsolete air-wave determination of the time. In the second period, 1927-1928, a shot-to-receiver distance of 5-6 miles was used and radio transmission of the time of the explosion had replaced the air-wave method; practically the whole Gulf Coast salt-dome area was shot, without regard to previous shooting. A third re-shooting of the Gulf Coast, begun in 1928 with areal contouring of certain key seismic horizons, is now in progress; some contouring was done in the first period, but now little attention is paid to it on account of the low accuracy of the air-wave determination of the time of the explosion; contouring with the seismic method involves profile shooting, which is much slower and more costly than fan reconnaissance; the shooting of the whole salt-dome area by this method progresses slowly and

may never be completed. The fourth re-shooting of the Gulf Coast salt-dome area began with the search for the very deep salt domes and the increase of the effective depth range of fan reconnaissance to 7,000-8,000 feet; much of the area previously shot with fan reconnaissance effective to 4,500 feet will be re-shot. Many gaps were left in the earlier work, particularly where fans came together and in places which were difficult to cover; the shooting maps are being re-studied and those gaps are being shot. With this period of the fourth re-shooting, two new tendencies in the evolution of the seismic technique are developing. The first is a tendency toward abandonment of the use of the travel-time of the air wave for the determination of the distance between shot and receiver positions. The reconnaissance for very deep salt domes involves longer shots and the use of very much smaller anomalies. An attempt is being made to perfect the technique to such a point that anomalies of $\frac{1}{10}$ second "advance" or even slightly less may safely be regarded as significant. The distances determined from the travel time of the air wave on 8 and 9-mile shots have been proving too inaccurate and the tendency now is to survey the distances. The second tendency is toward the use of vertical or very high-angle reflection in the surveying of particular prospects. This type of reflection shooting has not been entirely accepted, but the Geophysical Research Corporation seems to have confidence in it.

UNITED STATES OUTSIDE GULF COAST

In the United States outside of the Gulf Coast petroleum province, the seismograph, torsion balance, and magnetometer have been used to some extent in California, West Texas, and eastern New Mexico, the Texas fault-line district, Oklahoma, Kansas, Arkansas, northern Louisiana, Michigan, Colorado, Wyoming, and probably elsewhere. The electric methods were used slightly, but the work was largely in the nature of experimental application of them to determine their practical worth. Since the discovery of the Van oil field in northeast Texas, there has been renewed use of the seismic method in northeast Texas and the first considerable attempt to use the torsion balance there.

FOREIGN COUNTRIES

In foreign countries, considerable use of geophysical methods of prospecting for oil continued in Venezuela, Mexico, and Roumania, and there has been some use of these methods in Germany, Italy, France, Egypt, Angola, Australia, Persia, Canada, and other countries.

EVALUATION OF METHODS

Opinion about the value of the geophysical methods in other than
salt-dome areas is somewhat divided. Some companies are well satisfied
with the results of their work in non-salt-dome areas. Other companies are
dissatisfied with the results of their work in the same areas and are skep-
tical of the value of geophysical methods. Some companies are uncertain
in regard to the value of these methods.

Each of the four main methods, seismic, torsion balance, magnetic,
and electric, has been used with some success in mapping structure. The
torsion balance and magnetometer have to their credit the discovery of
the Hobbs oil field and structural "high" by the Midwest Refining Com-
pany and the Vacuum Oil Company-Rycade Oil Corporation's well near
Lovington, New Mexico, a ridge of igneous rock in the Oxnard plain,
California, and some igneous masses in Arkansas. Buried ridges, such
as the Amarillo granite ridge and the Nocona-Muenster "granite"-
Ordovician ridges, are conspicuous in torsion-balance and magnetometer
surveys. The Era continuation of the Muenster ridge was discovered
by the torsion balance. Such petroliferous structures as Healdton,
Hewitt, and Robberson, are prominent in torsion-balance surveys.
The effectiveness of the electric method has been demonstrated in the
mapping of Darst Creek and seemingly is showing potentialities of con-
siderable importance in the electric logging of wells. The seismic method
has been used with considerable success in mapping faults and contouring
key beds under certain geologic conditions, for example, the Viola lime-
stone in the Seminole district and the Austin chalk in northeast Texas.

Several failures, or seeming failures, however, are being charged
against the geophysical methods on account of tests drilled in non-salt-
dome areas. These tests were failures commercially, for they failed to
find oil, but they do not necessarily represent a hopeless failure of the
respective geophysical methods that caused the location of the tests.
Some of the failures may represent complete failure of the respective
methods. Others are the result of the bungling use of the geophysical
methods by executives or by incompetent interpreters. Some are due
to the youth of the methods and the inadequacy of experience in inter-
pretation of their results. Many probably are due to only a 10-25
per cent failure of the respective methods. Many are caused by the
play of low-grade geophysical prospects in the absence of available
high-grade prospects.

The evaluation of the true significance of these failures and of the
final places of the respective methods in the mapping of non-salt-dome

structure is not yet possible. Many of the failures which are being charged against the geophysical methods are based on single and isolated wells. A considerable knowledge of the geology of the respective areas is necessary for the explanation and evaluation of those seeming failures, but unfortunately, in most of those areas our knowledge of the geology is extremely scanty. In the Gulf Coast region of Texas and Louisiana, the evolution of geophysical exploration has progressed much farther than anywhere else in the world; much more geophysical work, chiefly seismic and torsion-balance, has been done, and there has been more drilling on more geophysical prospects than anywhere else in the world. The normal structural stratigraphic situation is extremely simple, and the structures mapped, the salt domes, are extremely exaggerated structures which present certain somewhat simple physical anomalies. The structural and physical situation, therefore, in many ways is very much simpler than the structural and physical situation in non-salt-dome areas. The geophysicist has been able to learn more about the significance and interpretation of the anomalies which he maps and has been able to develop the power of the torsion-balance and seismic methods to a much higher degree than it has been possible to achieve in non-salt-dome areas. The application of the geophysical methods in non-salt-dome areas shows signs of being in a stage of evolution comparable with one of the earlier stages of the evolution of the application of the geophysical methods in the Gulf Coast region. The history of the geophysical methods, particularly of the torsion balance on the Gulf Coast salt domes, may afford a lesson of what we may expect of the geophysical methods in non-salt-dome areas.

HISTORICAL REVIEW OF TORSION-BALANCE AND SEISMIC METHODS IN GULF COAST REGION

An outline of the history of torsion-balance and seismic methods in the Gulf Coast region is given in Table III.

TORSION-BALANCE METHOD

The gravitational system in the salt-dome area consists of (1) the salt plugs of a specific gravity of 2.19 ± 0.03[1];(2) a cap of limestone, gypsum, and anhydrite which lies on the salt and which has a specific gravity of 2.6 ± 0.2[1]; (3) a 15,000-20,000-foot stratigraphic section of Tertiary sediments, the specific gravity of which ranges from 1.9 to 2.1[1] within 500 feet of the surface to 2.2[1] $\pm$ at 2,000-3,000 feet in depth, and probably

[1]In part from determinations from hand specimens and in part from theoretical deductions and calculations in connection with torsion-balance surveys.

TABLE III

TABULAR HISTORY OF TORSION-BALANCE AND SEISMIC METHODS IN GULF COAST
REGION OF TEXAS AND LOUISIANA

	Torsion Balance	*Seismic*
1922	Introduced into America	
1923	MAPPING KNOWN DOMES	
		Introduced into Mexico
		Introduced into Oklahoma and north Texas
1924	Reconnaissance for maxima	
	Discovery of: Nash	Introduced into Gulf Coast region
	Long Point	Mechanical seismographs
	Clemens	Air-wave timing. Surveyed distance
	Allen	2-3-mile shots. Fan reconnaissance
1925	SHALLOW DOMES ERA	Attempted profile mapping of top of Miocene. Shallow domes discovered
1926	Torsion balance largely discredited for reconnaissance and used mainly for detailing shallow domes	Wireless timing. Air-wave distance. Mechanical-electric seismographs. 3-6-mile shots. Mainly fan reconnaissance. Many shallow and deep domes discovered
1927	Lost Lake, Edgerly, Roanoke, and several maxima drilled and condemned at the beginning of the era	
	DISCREDITED ERA	
1928		
	Active reconnaissance for deep and very deep domes. Dewalt, Hankamer, Esperson found on deep and very deep domes mapped by torsion balance	Wireless timing. Air-wave distance. Mainly electric seismographs. 6-8-mile shots on fan reconnaissance for deep and very deep domes. Profile contouring of seismic horizons. Attempted critical-angle reflection shooting
1929		
1930	DEEP DOMES ERA	Surveyed distance replacing air-wave distance. 7-10-mile shots on fan reconnaissance for very deep domes. Profile contouring of seismic horizons. Vertical-reflection shooting

to 2.3 or 2.35[1] or possibly slightly more at very great depth. The relative density of the cap rock with reference to the surrounding sediments is positive and fairly large; the relative density of the highest part of the salt in a very shallow dome may be positive but very small; from 1,000 ± to 5,000 ± feet there is a thick zone in which the salt has essentially the same density as the surrounding sediments; below 5,000 ± feet, the relative density is negative and probably increases with depth. The gravity anomaly of an average shallow dome, therefore, consists of: (1) a fairly sharp gravity maximum essentially coincident in position with the top

[1]From theoretical deductions, both geological and geophysical.

of the dome, but not extending more than 750 feet out from the edge of the dome, and (2) a broad shallow minimum concentric with the dome and extending out 6-8 miles from the center of the dome. If the dome does not rise within 3,000 feet of the surface, it is represented only by a minimum.

In the first or "Shallow domes" era of the torsion balance in the Gulf Coast region, the study of the known domes established the maximum as the characteristic gravity anomaly of the salt domes, for only one of the known domes was as deep as 2,000 feet. Exceptional domes were known, however, with minima, but none of the surveys was carried out far enough completely to map a minimum, and the minima were not well understood. When reconnaissance commenced, the search was wholly for maxima of the type which had been learned as characterizing the known domes. The four maxima, Nash, Long Point, Allen, Clemens, all of that characteristic type, were mapped and soon confirmed as salt domes by the drill. The succeeding maxima mapped were not of the characteristic type, but were more irregular and fainter and had a different type of cross profile. These non-typical maxima were interpreted as being possibly, but not probably, "deep" salt domes (deep in the 1925 sense, not in the 1929 sense). The prospects with which many of the non-typical maxima were associated had surface indications which justified drilling (oil in shallow wells, H_2S in a 90-foot water well, water whose analysis suggested a deep-seated water rather than a surface water). Many such maxima were drilled with entirely negative results. Three distinct, regular minima were mapped by the Roxana (now Shell) Petroleum Corporation during late 1924 and 1925, East Edgerly, Lost Lake, and Roanoke (Roanoke, simultaneously mapped also by the Rycade Oil Corporation). These minima were drilled with entirely negative results, Lost Lake and Roanoke to 4,000± feet and East Edgerly to 5,200 feet.

The "Discredited" era of the torsion balance in the Gulf Coast region opened with these complete failures of tests on the minima and the non-typical maxima. As a result of these failures, minima were somewhat generally regarded as condemned as indications of anything of interest to the oil man, and maxima were regarded as unreliable indications of salt domes, although the interpreters argued that the typical maxima were entirely reliable criteria. About the same time, the seismic method began to demonstrate its high economic superiority over the torsion-balance method in reconnaissance for shallow and relatively shallow domes. The torsion balance, therefore, was almost entirely

discredited for reconnaissance for salt domes and work with the torsion balance almost ceased in the Gulf Coast region except for minor work on detail surveys of the crests of shallow domes.

New data began to accumulate about the supposedly discredited minima toward the end of the era and during the beginning of the succeeding era. The Lost Lake dome was discovered near the center of the Lost Lake minimum and was confirmed by the drill. It now is evident that the Roxana (now Shell) Petroleum Corporation's well would probably have gone into the salt if it had been drilled to a depth of 6,000 feet.

The salt was drilled into at Edgerly in an area which is about ½ mile southwest of the Roxana (Shell) Petroleum Corporation's 5,200-foot well and which is on the northeast edge of the Edgerly oil field. The Dewalt (4,000 feet) dome was discovered by a North American Exploration Company party working for H. C. Cockburn, and independently but slightly later by a Humble Oil and Refining Company seismograph troupe. The presence of the dome was confirmed by the drill, and oil was discovered in 1928.

The "Deep domes" era of the torsion balance in the Gulf Coast began with the discovery of the Dewalt oil field. The significance of the discovery was not appreciated generally and only a few operators began reconnaissance for deep domes. A second test at Roanoke during the spring of 1929 discovered oil, but not in commercial quantity. During the following summer the Esperson and Hankamer oil fields were discovered by tests which were drilled on torsion-balance minima. The seismic geophysicists did not think well of either prospect, although a faint anomaly had been mapped at Esperson. Although the Dewalt dome was found by the seismograph almost simultaneously with its discovery by the torsion balance, the dome had been missed in much other seismic work. Recognition gradually became general that the condemnation of the minima on account of the failures of the tests at East Edgerly, Lost Lake, and Roanoke had been premature, that those minima were the anomalies of very deep domes, that the torsion balance is not only serviceable in detecting deep and very deep salt domes, but in discovering domes which were being missed by the current practice of the seismic method, and that it had (and still has) a slight superiority over the seismograph in reconnaissance for the very deep salt domes (except in areas of bad marsh and water). By the end of the year, eighty torsion balances, more or less, were in use in the Gulf Coast region, mainly on

reconnaissance for new salt domes, and several companies are engaged in making a fairly complete areal torsion-balance survey of the Gulf Coast.

A great development in our knowledge of the geophysical and geological significance of the gravitational anomalies has accompanied the coming of the "Deep domes" era. The interpretation of the "Shallow domes" era was based almost wholly on the empirical study of the then known (shallow) domes on the basis of surveys which are now known only partly to cover the anomalies of those domes. Many additional data are available now; the theory of interpretation has developed further, and analysis of the gravitational system of the Gulf Coast has brought a fair understanding of the gravitational anomalies.

The large definite minima are recognized as being the anomalies of salt masses mainly lying below a depth of 4,000 ± feet. These minima may be subcircular, or linear. The subcircular minima are known definitely to be the characteristic type of anomalies produced by deep and very deep[1] salt domes and by the roots of shallow domes.

The interpretation of a certain type of very large minimum, however, has not been entirely settled. Minima of other types theoretically are possible and probable.

The linear minima on the basis of geological and geophysical reasoning are interpreted as very deep salt ridges.

The maxima of the Gulf Coast area are of at least four types produced by quite different causes. A certain type characterized by a relatively narrow zone of relatively large maximum gradient is the anomaly associated with shallow domes and is produced mainly by the cap rock, but also in part by the salt mass, if the salt is very shallow. A second type, which was the cause of many of the negative tests on maxima at the beginning of the "Discredited" era, is produced by the interference of the minima of deep domes or of the roots of shallow domes. This type of maximum also may be thought of as the anomaly of the prism of sediments between the salt domes. A location for a test on such a maximum will be the most unfavorable one possible on the Gulf Coast, as it will be essentially midway between domes. A third type may be produced by sedimentary irregularities of density in the upper 1,000 or 2,000 feet of the section. During the "Discredited" era, most of the maxima which were not of the type characteristic of the shallow domes commonly were interpreted as due to "gravel" beds. A fourth type, produced by

[1] A deep salt dome in 1924 meant a dome lying at a depth of 2,000 feet or more; at present, it means a dome lying at a depth of 4,000 feet or more. The writer uses the term "very deep domes" for domes lying at a depth of 7,000+ feet.

a structural dome not associated with a salt dome, is possible, but thus far the writer has seen only one anomaly which may possibly be of this type.

Analysis of the gravitational system which produces one of the characteristic minima shows that although a minimum may definitely indicate the presence and approximate position of a deep dome, considerable and inescapable indefiniteness exists in its indication of the position and depth of the crest of the dome and in the probability of deformation of the potentially petroliferous super-salt horizons. The salt in the neutral zone has the same density as the surrounding sediments, and in the immediately underlying zone, the salt is only very faintly lighter than the surrounding sediments. The upper part of the salt of a deep dome, therefore, does not produce an appreciable gravity effect at the surface and its conformation can not be determined gravitationally.

The minimum reflects the salt mass as a whole from 5,000 ± feet down to 15,000-20,000 feet, but the conformation of the top of the salt mass largely controls the deformation of the super-salt beds and the localization of the accumulation of the oil. If interpretation of the position of the center of the dome is based on the position of the center of the minimum, the presence of a regional gradient may produce a shift of the apparent center of the dome; the amount of the shift may not be determinable. If the position of the dome is determined by semi-quantitative calculations, the errors of observation produce some indefiniteness in the results of the calculations. Geologically, as far as we can reason at present, uplift of a salt dome may cease at any period. In some of the deep salt domes, uplift may have ceased in early Tertiary time with no subsequent recurrence. In others of the deep domes, uplift may have continued into the Pleistocene or to the present. On the former domes, there would be no deformation and no accumulation in horizons of later age than the date of the last uplift and, unless tests go below these horizons, the drill finds no confirmation of the presence of the dome. The results of drilling on well defined minima are in conformity with the expectations deducible from those arguments. Many of the minima, St. Martinsville, Egan, Genoa, Clodine, Shepherds Mott, Beasley, Needville, have been drilled with negative results. Sufficient showings of oil have been obtained in drilling at Roanoke and Mykawa to justify the expectation of the presence of the dome and production tangent to the wells which obtained the showings, but the exact position of the uplift has not been found. At Esperson the first well was entirely negative;

the second showed the probable presence of uplift on the top of the Jackson; and the third discovered the oil. At Hankamer, the first test was entirely negative. According to the permutations possible under the laws of chance, there was a considerable chance that the fourth, fifth, and sixth tests on the minima in the Gulf Coast region might have been the negative tests on any three of the minima, St. Martinsville, Egan, et cetera. There would then have been six good tests on minima with entirely negative results and the minimum would have been regarded by general geologic opinion as entirely condemned.

A fairly complete areal torsion-balance survey of the coastal salt-dome area, made during the "Discredited" era would have been enormously valuable to a company at the beginning of the "Deep domes" era, when the importance and significance of the minima began to become evident. Areal mapping with the torsion balance is so slow that the company would have been able to block as many of the minima as it desired and to have checkerboarded the remainder with protection leases before competing companies without such completed area surveys would have been able to do enough areal reconnaissance definitely to have outlined any of the minima. A half interest in the lease block on two of the better minima could then have been sold for enough almost to have reimbursed the company for the cost of the areal torsion-balance survey.

SEISMIC METHOD

The development of the seismic method, unlike that of the torsion-balance method, has been rather steady, but likewise is divisible into three periods which coincide more or less with the three eras in the history of the torsion balance in the Gulf Coast region.

In the first period, which may be called the "Air-wave time or Shallow dome" period, all the effective seismic prospecting in the Gulf Coast region was done by Seismos with its mechanical seismograph and with the air-wave determination of the time of the explosions. On account of the limitations of the air-wave determination of the time of the explosion and on account of a belief in a theoretical impossibility of effective work at a distance of more than 3 miles, shot lengths of less than $2\frac{1}{2}$ miles were used and the seismic prospecting was effective down to a depth of 2,500 feet. The Seismos troupe attempted considerable profile mapping on the top of a seismic horizon which they termed "the top of the Miocene," and which lay at a depth of 2,000 ± feet. Many faults were discovered on the basis of this profile mapping. A very large part of the Gulf Coast area between Lafayette, Louisiana,

and Wharton, Texas, was explored by the seismic method during this period and one of the four crews was very effective in discovering domes.

The second, or "Moderately deep domes" period was initiated by the appearance of the American electric seismographs with wireless determination of the time. The electric instruments made feasible the prospecting of the coastal marshes and shallow bays. The introduction of the wireless determination of the time of the explosion reduced considerably the error of observation. A Geophysical Research Corporation troupe showed the practicability of 5-mile shots by discovering the Moss Bluff salt dome on some long shots (undertaken against orders). The increase of the shot length on reconnaissance to 5 miles increased the effective depth range of the method to 4,500-5,000 feet. Most of the leases shot during the first period were re-shot and much new area was explored, comprising chiefly the coastal marshes and shallow bays and the Mississippi delta and bottoms. Areal profiling of seismic horizons fell into disrepute during this period, but began to come back into favor toward the end of the period. The reconnaissance was almost wholly fan reconnaissance for anomalies showing indications of "salt velocity." The geophysicists reported anomalies which did not show the "salt velocity," but which seemed indicative of some sort of geologic structure. The geologic significance of those irregularities, however, was not known and they were neglected.

The third or "Deep domes" period is in part a reaction to the developments in the torsion-balance method and in part a natural development within the seismic method. Esperson and Hankamer were torsion-balance minima which were rated by the seismic method as very dubious prospects. Confirmation by the drill of the torsion-balance indications showed that the seismic method was failing to detect certain types of dome. Port Neches was discovered by The Texas Company on the basis of one of the non-typical anomalies which were being disregarded and showed that that type of anomaly in some places was indicative of a very deep salt dome. More care and attention were then given to these less pronounced anomalies which are produced by the deformation of the super-salt sediments above very deep domes. In order to handle fainter anomalies, attempts were made to decrease the error of observation; a tendency began to be displayed to substitute surveyed determination of the distance between shot and receiver for the air-wave determination of the distance and also to plant the shots at a depth of $100 \pm$ feet. In order to reach greater depth, the shot length on reconnaissance was increased to $9 \pm$ miles. Much profile contouring of seismic horizons

was done, but largely on prospects rather than on general reconnaissance. Considerable reflection shooting was being done, this also chiefly on prospects. Considerable use was made of the seismic method in attempting to detail deep or very deep prospective domes discovered by the torsion balance. Much of the area shot during the preceding two periods was re-shot during this period.

A fourth period possibly is now beginning. There is considerable indication that the refraction method and the whole use of the seismic method for rapid reconnaissance for salt domes is on the decline, but that the reflection seismic method is only at the commencement of a period of at least considerable usefulness in the Gulf Coast region. The costs of the refraction method were high and are increasing on account of the technical difficulties of detecting a very deep dome, and the rate of discovery of new domes per troupe per year is decreasing. In using the refraction method in the fan type of rapid reconnaissance which was so brilliantly successful in the past, it is now necessary to use anomalies whose magnitude approaches that of the probable error of observation. The reflection method has been developing rapidly during the past year and has shown increasing power. It is, however, a detail method, and reconnaissance with it is slow and expensive. Its final place in geophysical prospecting in the Gulf Coast region has not been established, but the writer suspects the coming period in this region will be the "Reflection" period.

LESSONS APPLICABLE IN NON-SALT-DOME AREAS

Several lessons may be drawn from the experience with the geophysical methods in the Gulf Coast region and applied with profit to the evaluation of the geophysical methods and their seeming failures.

The danger of too hasty condemnation is exemplified by the experience with the gravity minima in the Gulf Coast region. An isolated test on a geophysical prospect is not ordinarily a safe criterion of the failure of the geophysical method or methods by which the prospect was located. Geologists are accustomed to pronounce definite judgment that an isolated dry wildcat is "normal" or "low." The first three tests on the minima on the Gulf Coast were "normal." A dispassionate, philosophical survey of the data on which correlation of such isolated tests has been based commonly will show them scanty and inadequate. There are many reasons why in many places a geophysical indication of structure may be almost right but be sufficiently wrong so that the first test will be a failure. But few geological predictions are 100 per cent correct

and not uncommonly on a "geological" structure several tests have to be drilled before one is located correctly. Eaton states that the better geologic departments of California oil companies average one success to nineteen failures. Yet geophysical prospecting is condemned in California on the basis of a very few tests on geophysical prospects, most of them not first-class prospects.

A geophysical method may give definite indications of the presence of some type of geological structure, but may not delineate the details of the structure with sufficient clearness to permit the accurate location of the first tests. A gravity minimum in the Gulf Coast region may indicate definitely the presence of a deep salt dome, but it gives a somewhat poor indication of the exact position of the crest of the dome. But in oil geology, an indefinite indication of structure is of value in the absence of more definite indication of the structure.

The personal equation enters into the success of a method. Working with identical instrumental equipment under identical conditions, one man may make a success of a method and another may make a failure of it. Seeming failure of a method may be a failure of the personnel and not of the method.

Success may not be possible with the use of a geophysical method in a particular region until considerable knowledge has been acquired of the geophysical characteristics peculiar to the different types of structure in the area. The stratigrapher has to work out his stratigraphic section before he can begin his work of correlation. The oil geologist has to learn whether the oil accumulation is anticlinal, synclinal, or controlled by a water level midway on a flank before he can make correct locations for tests. The geophysicist similarly must learn much about the geophysical reactions of his area before he will begin to understand the significance of the anomalies which he maps. And until that time he may be unable to distinguish accurately between anomalies such as the maxima of the Gulf Coast which definitely represent desirable structures and the other type of maxima which are the most unfavorable locations in the Gulf Coast region.

Failures on prospects which are marginally favorable should not be charged against a method. A great many prospects are drilled because the company has no better prospect available. A great many prospects have been "farmed out" by their discoverer company because the company felt that the prospect did not justify the expenditure of the company's money for a test.

One geophysical method may be preferable for one purpose and another method for another purpose, and one method may be preferable in one area and another method in another area. The seismic method was superior to the torsion-balance method in reconnaissance for shallow domes, and the torsion-balance method had certain advantages in detailing the crests of shallow domes discovered by the seismic method, but in the reconnaissance for deep salt domes, the torsion-balance method has certain advantages, and the seismograph is used to detail deep domes found by the torsion balance. One type of structure in one place may be detected by one method and not by another, and vice versa.

Obsolescence is of considerable importance in connection with the observations which have been made, the surveys made, and the interpretation made from the surveys. The earliest magnetometer observations in this country are largely obsolete on account of the very much higher error of observation with the early instruments. The early "air-wave-time" seismic work is obsolete on account of the inaccurate determination of the time of explosion under the air-wave method. Much of the seismic work of the second period is half obsolete because the grade of the work does not measure up to present standards. Some of the areal torsion-balance work will become obsolete because speed is emphasized rather than accuracy; an accuracy is being maintained which is sufficient for present purposes, but which may not be sufficient in the future. Some of the earlier torsion-balance surveys are obsolete, although the individual observations will never be obsolete; these are surveys which were run with too wide a station interval for the purposes of the present day interpretation, but if the necessary intermediate stations are occupied, the survey will be as good as if all stations had just been taken. Interpretation rapidly becomes obsolete; our experience is growing rapidly, and interpretation made several years ago may be entirely erroneous in the light of present knowledge. A report made five years ago on an inter-dome maximum in the Gulf Coast region might have been mildly favorable, although now such a prospect would be recognized as most unfavorable.

Regional geophysical surveys ultimately may be enormously profitable to the company which made them, although at the time of the survey interpretation of the anomalies may not be possible. A regional survey reveals many relations which otherwise would be obscure. The significance of the gravity anomalies of the Gulf Coast, for example, did not become evident until regional surveys were made. Even if the shallow domes were the only domes in the Gulf Coast region, it would be

impossible to understand the gravity anomalies produced by them until much areal mapping had been done. Regional mapping, therefore, will expedite the understanding of the anomalies which it discloses, and in many places the interpretation of anomalies is not possible until extensive areal surveys are available. A company which makes areal surveys will learn the secret of the significance and interpretation of the anomalies a little sooner than a company which does not make areal surveys. When the significance of a petroliferously favorable type of anomaly does suddenly become clear, an areal survey which shows the various anomalies of that type will be of great commercial value. Geophysical surveying is slow and it takes much time to make areal surveys. A company which has already made its areal survey will be able to select and to block the most favorable of the anomalies and to checkerboard the next most favorable anomalies with little effective competition from rival companies. A torsion-balance survey of the coastal salt-dome area made by a company during the "Discredited" era of 1926-1927 would have been most profitable to the company in 1929.

CONCLUDING THOUGHTS

In conclusion there are three thoughts which the writer would like to express.

The geophysical methods, both individually and in combination, furnish no easy means for the detection and mapping of petroliferous geologic structure and for the discovery of commercial deposits of petroleum. They are merely one set of tools of the oil geologist, and like his other tools, they have their uses and their limitations. Surface geology gives brilliant indications of the subsurface structure in many areas, but if the surface beds are thick, and very cross-bedded, surface geology may give a very erratic indication of structure; if no exposures are available or if the surface beds do not reflect the subsurface structure, surface geology is of no value. Paleontology is an important tool of the oil geologist, but it can be of use only if fossils are available and, in many situations, it is an erratic tool. Each of the main geophysical methods has been distinctly effective in indicating certain structural conditions, some of them so successfully as to suggest clairvoyance. Combinations of methods have been effective in indicating conditions which neither could indicate satisfactorily alone. Some of the methods under special conditions primarily are reconnaissance methods and will not give the details of structural features which may have been detected by their use. There are structural situations which can not be met by any one, or by

any combination of the methods. One structure may be mappable by an interpretation of surface geology or of fossils and an adjacent structure may not; similarly, one structure may be mappable by geophysical methods and another may not; and the inadequacy of a geophysical method in the attempt to map one structure is no necessary evidence of its inadequacy for the mapping of other structures in the same area.

Oil geology is recognized as an inexact science which is of value because, inexact though it is, it ultimately reduces the chances of failure and increases the chances of success in the discovery of oil. Perhaps on account of the seeming ability of the geophysical methods to see down, as it were, into the earth, general opinion tends to credit them with a power of clairvoyance which they do not possess. The geophysical method of mapping structure is, like oil geology, an inexact science, although in restricted areas, like geology, it may seem almost to be an exact science. But, inexact though it is, it gives important clues to structure in places where geologic evidence is scantier or absent. The geophysical methods, therefore, should not be regarded as infallible indicators of structure, but as another method of reducing the chances of failure and increasing the chances of success in finding oil in places in which it is impossible to do satisfactory geologic work.

Every definite anomaly which actually exists—which is not due to errors of observation—has some geologic significance. The anomaly is produced by some geologic inhomogeneity in the earth's crust and is telling us of that inhomogeneity in a language which we may or may not be able to understand. Even the rather despised magnetic maxima of the Mid-Continent must be indicating some geologic feature. The commercial geologist is interested only in a limited range of geologic features. The task of the geophysicist, therefore, is to learn to understand the language of these anomalies and to distinguish the anomalies which are indicative of the structures of interest to the commercial geologist and to learn to understand what they are telling about those structures.

The many anomalies which have been mapped by areal surveys in West Texas, Oklahoma, Kansas, and California, and whose significance as yet is not wholly evident, must be indicating geologic features. Presently their significance will become clear and some of the anomalies will be found to be indicating structural and non-structural geologic features, but the writer feels confident that many of them will be found to be indicating something about the petroliferous types of structure which the oil geologist is seeking.

Isogam maps of magnetic or gravitational surveys, maps of equal electric resistivity, and equipotential maps, look seductively like structure-contour maps. With simple, symmetrical or almost symmetrical structures, there may be a seductive correspondence between the isogams, et cetera, and the structure-contours which leads the unwary to believe that isogam maps, maps of equal resistivity, and equipotential maps, may be used directly as structure-contour maps, and to believe that to discover a structural "high," it is necessary only to discover a gravity "high," a magnetic "high," et cetera. But unfortunately maps of that character show only the surficial variation of a physical effect. A relation does hold between that surficial variation of the physical effect and the conformation of the subsurface, but the relation is expressed only by complicated mathematical formulas. Asymmetry of the body producing the anomaly will produce a divergence in position between the structural crest and the center of the gravity or magnetic crest. At the magnetic poles, the center of the anomaly of the vertical component tends to be central over the body producing the anomaly, and the center of the anomaly in the horizontal component tends to be offside, but at the equator the situation is reversed. The anomaly produced by a vertical cylinder $\frac{1}{2}$ mile in diameter and $\frac{1}{2}$ mile to $1\frac{1}{2}$ miles in depth theoretically extends to infinity, and, practically, it will be appreciable in magnitude out to a distance of 2 miles from the axis of the cylinder, if the anomaly as a whole is appreciable. Structural "highs" may be represented by gravity maxima or minima, and a few rare structures, such as some shallow salt domes in the Gulf Coast region, may be represented by a maximum within a larger minimum. Structural "highs" may be represented by a magnetic maximum or minimum, or paired maxima and minima. The statement holds, for all practical purposes, that no simple transformation of isogams and similar lines of equal physical effect into structure contours is possible; that it is not possible to multiply isogams by some constant and obtain structure-contours.

Isogams and similar lines of equal physical effect must be translated into terms of structure. Roughly approximate structure contours can be calculated in a very few, exceptionally simple situations. But, in general, the calculations give only a qualitative picture of the structure and do not give structure contours which have any significance in feet or other similar unit of measure. By simple inspection, a skilled interpreter may be able to translate a simple anomaly into terms of structure, but the act of translation is there. In a rare area of simple geologic and physical structure, a simple direct relation may hold between struc-

tural "highs" and the geophysical maxima and minima, and in such an area the naïve and simple interpretation of geophysical maxima (or minima) as automatic, simple indicators of corresponding structure will be successful. Unfortunately, however, satisfactory interpretation ordinarily involves much more than the simple discovery of the geophysical maxima (or minima) and an analysis must be made which involves a knowledge of the mathematics of interpretation as well as of the known, probable, or possible geophysical reaction of known, probable, or possible formations and structures in the area.
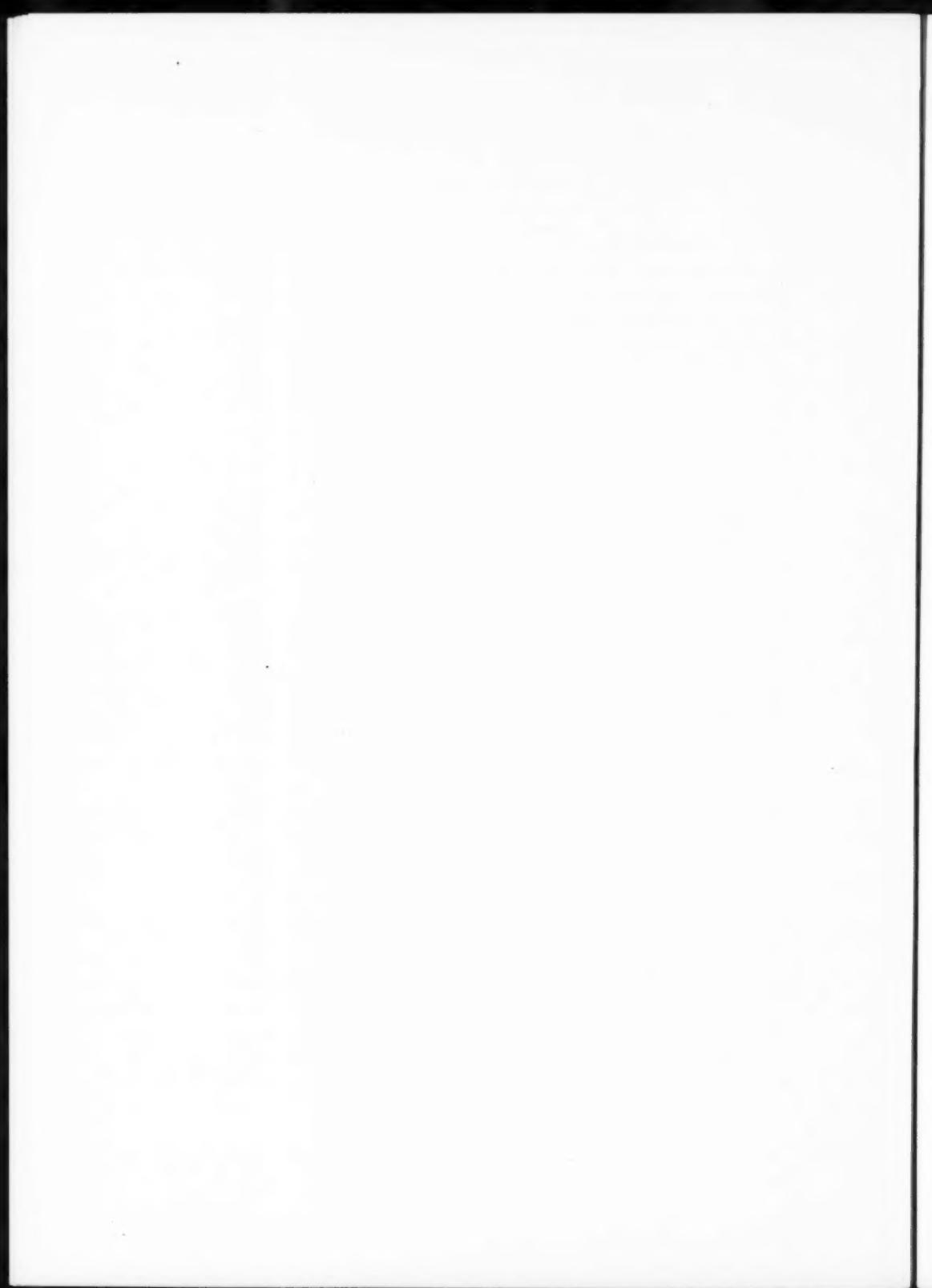
TORSION-BALANCE SURVEY OF ESPERSON SALT DOME, LIBERTY COUNTY, TEXAS[1]

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Houston, Texas

ABSTRACT

The Esperson salt dome was discovered in a torsion-balance survey made by the Union Exploration Company late in 1928. The discovery well of the oil field on the dome was completed in the summer of 1929. The torsion-balance survey showed the presence of (1) a large minimum indicating the Esperson dome, (2) a similar minimum due to the South Liberty-Dayton salt dome, and (3) two maxima, one of them due to the interference effect of the Esperson and South Liberty-Dayton minima, and the other to the interference effect of the Esperson minimum and the minima of the Moss Bluff, Lost Lake, and Barbers Hill salt domes. The approximate form and position of the Esperson dome on a northeast-southwest profile were calculated by the writer's chart method. The calculations seem to indicate that the respective salt cores of the Esperson and South Liberty-Dayton domes must extend to a depth of 15,000± feet and be broader at the base than at the top. The center of the Esperson minimum is shifted about ½ mile south-southeastward from the center of uplift as approximately defined by drilling. Shifts of the center of the minimum away from the center of uplift may be due to (1) asymmetry of the dome, (2) regional gradient, (3) a spine of salt rising into the neutral zone, (4) local anomalies. A certain degree of indefiniteness is inherent in the torsion-balance indication of the exact position and depth of a deep salt dome, but additional uncertainty is produced by some methods of interpretation. The torsion-balance data offer no criteria for determination of the presence or absence of deformation of the super-salt beds. Four types of gravity maxima may be present in the Gulf Coast region: (1) salt-dome maxima produced by shallow salt domes, (2) inter-dome maxima produced by the interference effects of the salt-dome minima, (3) structural maxima, and (4) sedimentary maxima.

INTRODUCTION

Location.—The Esperson dome, also known as the Sheeks dome, is about 30 miles northeast of Houston and is in the southwest part of Liberty County. It lies immediately south of the Southern Pacific Lines' main line east from Houston to Beaumont and of the Old Spanish Trail between Houston and Beaumont.

History.—The Esperson salt dome was discovered by a torsion-balance survey made by the Union Exploration Company (now merged with Cranfill and Reynolds Oil Company) in the late summer and early fall of 1928. The report is current that the Union Exploration Company

[1] Read before the Association at the New Orleans meeting, March 21, 1930.

[2] Consulting geologist and geophysicist.

had information that a seismic irregularity had been found at that locality. The torsion-balance survey showed very strongly the probable presence of a deep salt dome. But before the prospect was drilled, the seismic work failed to disclose the presence of a dome, and as general opinion placed more dependence on the results of seismic work than on torsion-balance work, the prospect was regarded rather dubiously. One seismic troupe, however, reported that a very definite irregularity was present, but that the salt had not been detected. The first two wells drilled were dry, but showed differential uplift on the top of the Jackson in the amount of about 200 feet. The discovery well, Moores Bluff No. 1, was completed by Harvey Smith early in August, 1929, at a depth of 3,304-3,320 feet. It produced 800 barrels of 24° Bé. oil per day. By February of the following year, about eight producers had been completed with a mean daily production of approximately 2,000 barrels.

TORSION-BALANCE SURVEY

The major features of the gravity picture mapped by the torsion balance are: (1) a large minimum central around the oil field, (2) two somewhat lesser maxima respectively northeast and southeast of the minimum, and (3) the southwest edge of a big minimum in the extreme northeastern corner of the area surveyed (Fig. 1). The gradient ordinarily ranges from 2 to 7 E.[1] except on the profile to the northeast through the William Duncan survey; the gradient on that profile ranges from 5 to 12 E. As is common in areas of small gradient, the orientation of the gradient is somewhat irregular; notwithstanding that irregularity, the gradient clearly depicts the large minimum and strongly suggests the northeast and southeast maxima and the northeast minimum. Those two maxima and the northeast minimum are dealt with very incompletely by the present survey; therefore, they are not as well defined as the Esperson minimum.

The Esperson minimum is the surficial gravity expression of a deep-seated salt dome which seemingly controlled the accumulation of the oil to form the Esperson oil field. The form and limits of the uplift are not yet clearly outlined by the drilling. A tentative contouring of the structure of the oil field has been attempted in Figure 2, but is probably only a very inaccurate first approximation. The four wells which encountered the Jackson at the respective depths of 5,182, 5,381, 5,303, and 5,654 feet suggest very strongly that the center of uplift lies in the southern part of the C. W. Fisher Survey.

[1] Eötvös units = 10^{-9} dynes per gram per horizontal centimeter.
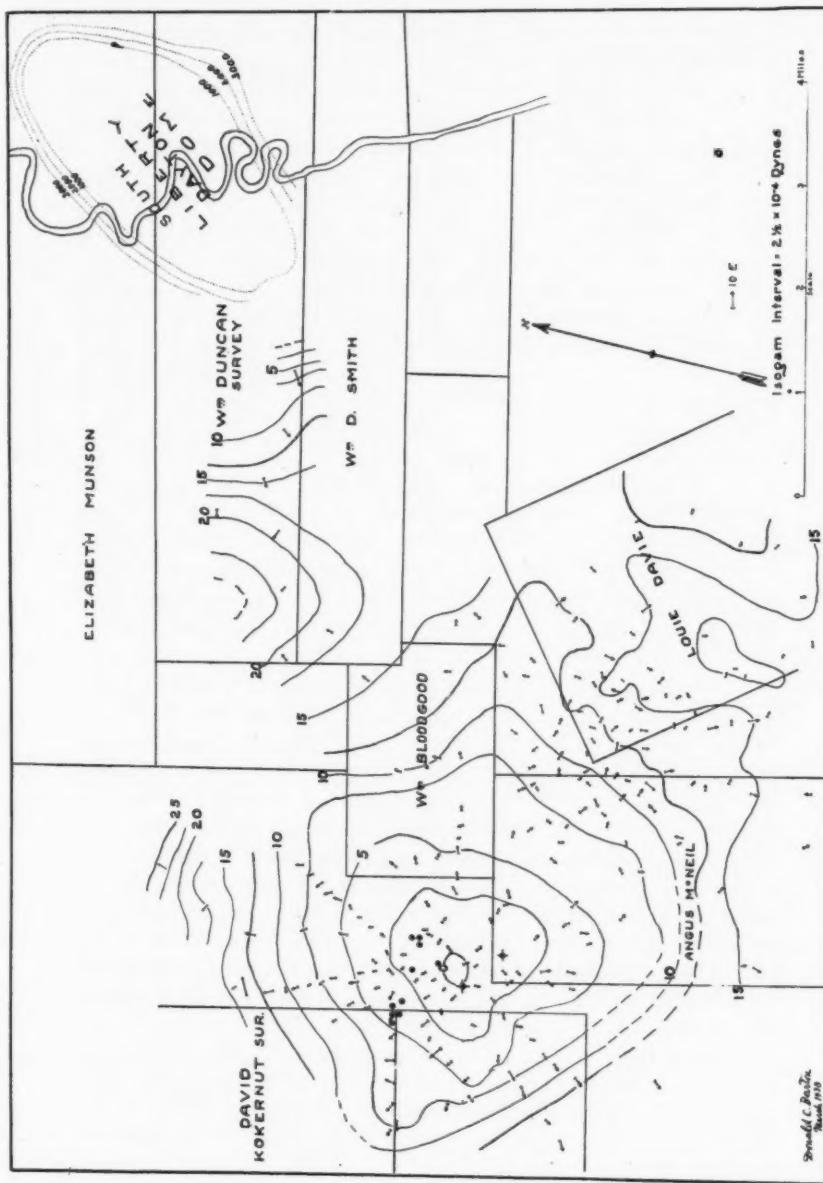
FIG. 1.—Torsion-balance survey of Esperson salt dome.   Gradient arrows from original survey by Union Exploration Company.
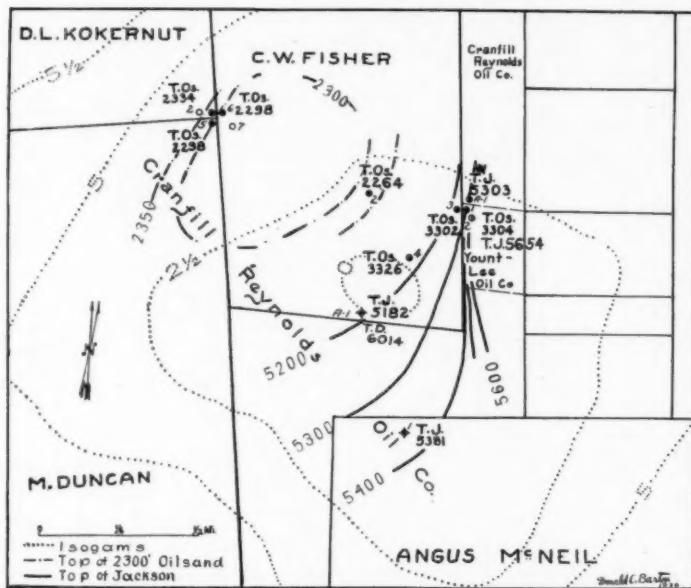
FIG. 2.—Sketch map showing relation of structure to gravity minimum.

Correlation on the 2,300-foot oil horizon suggests a northwesterly dip between the wells around the southeast corner of the D. L. Kokernut Survey, and, with well No. 2 in the center of the C. W. Fisher Survey, suggests that the center of uplift lies about ¼ mile southeast of the southeast corner of the D. L. Kokernut Survey. Lithologic and oil-sand correlation in the Gulf Coast region is inaccurate and unsatisfactory because the prevalence of many lensing sands makes it impossible to determine whether or not the same sand is used in different places. The delineation of the dome in Figure 2 is, therefore, subject to considerable change with the progress of future drilling. The center of the gravity minimum lies about ⅛ mile north of the Cranfill and Reynolds well, C. W. Fisher No. A1, and is approximately 1½ miles southeast of the center of uplift, shown in Figure 2.

The gravity minimum at the northeast corner of the area surveyed, in the main, is the minimum produced by the South Liberty-Dayton dome. The South Liberty-Dayton dome is one of the old known and much drilled domes. Structure contours based on drilling data are shown in Figure 1.

The last gradient values at the northeast end of the northeast profile are larger than can be accounted for by the effects of the South Liberty-Dayton dome and may be affected by local irregularities in the soil, or may mark the edge of the Trinity River valley.

The gravity maximum northeast of the Esperson dome may be regarded either as the interference effect of the two minima, the Esperson minimum and the South Liberty-Dayton minimum, or as the anomaly produced by the prism of sediments between the two salt domes. It is impossible to have two independent valleys without an intervening ridge and, similarly, it is impossible to have two independent minima without an intervening maximum. This maximum can be seen to lie exactly half way between the respective centers of the Esperson and South Liberty-Dayton salt domes.

If the anomaly of density is regarded as concentrated in the salt core and if the relative density is negative, each salt dome will produce a gravity minimum which will be appreciable for a considerable distance out from the edge of the dome, which is about $1\frac{1}{2}$ times the depth of the bottom of the salt mass. If two salt domes of equal size and depth are closely adjacent, the interference of their respective gravity minima will produce a gravity maximum midway between the two domes. If the anomaly of mass is regarded as concentrated in the prism of sediments between the salt domes and if the sediments are regarded as heavier than the salt, the prism of sediments necessarily will produce a gravity maximum centrally located above the prism of sediments.

The suggested maximum in the Louie Davie Survey southeast of the Esperson dome similarly is the maximum between the Esperson minimum and the minima of the Moss Bluff, Lost Lake, and Barbers Hill salt domes.

CALCULATED CROSS SECTION

The results of a quantitative study of the position and cross section of the Esperson dome are given in Figure 3.

The observed gradient profile is given by the solid line in the profile at the top of the figure. This profile is a resultant composed of: (*A*) the gradient profile produced by the Esperson dome, (*B*) the gradient profile produced by the South Liberty-Dayton dome, (*C*) a possible regional gradient, (*D*) the gradient profile produced by structure possibly smaller and probably shallower than the salt domes, and (*E*) local surficial irregularities.
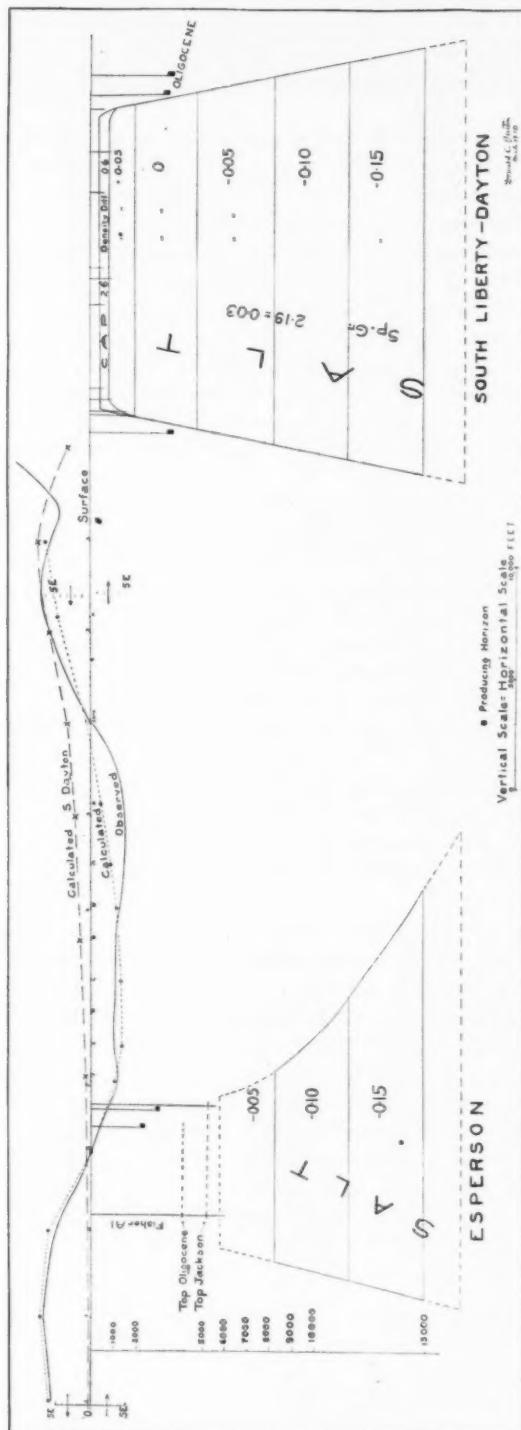
FIG. 3.—Calculated section across the Esperson and South Liberty-Dayton salt domes. Calculations by E. B. Summers under the direction of the writer.

The gradient profile of the South Liberty-Dayton dome can be calculated with a fair degree of approximation. The form, position, and composition of the dome are known to a depth of 4,000 feet. Assumptions must be made, however, in regard to the form of the dome below that depth and in regard to the ultimate depth of the dome. The density relations are known only approximately. The average specific gravity of the cap rock of the Gulf Coast salt domes is 2.6. On different domes, the specific gravity differs with the character of the cap rock, but in the present calculations, the cap rock of the South Liberty-Dayton dome is not an important factor because it lies at such a shallow depth that its lateral effect on the gradient is negligible within the areas of the present survey. The average specific gravity of the salt of the Gulf Coast salt domes is approximately 2.19, but may be as low as 2.16 or as high as 2.22. These figures are based on a considerable series of laboratory determinations of hand specimens made under the writer's direction and other determinations made by his colleagues. The figures also represent samples of salt from Texas and Louisiana domes. The specific gravity of the sediments is not well known. The writer's assumptions are that within the upper 500 feet of the surface, the specific gravity of the sediments ranges from 1.9 to 2.05 as an average and tends to be at the smaller value near the coast and the larger value farther inland; that from 2,000 to 4,000 feet, the specific gravity is about 2.20; from 4,000 to 8,000 feet, 2.25; from 8,000 to 12,000 feet, 2.30; and below that depth, 2.25, and possibly at a very great depth, 2.40. These assumptions are based in part on the laboratory determinations of specific gravity of cores at depths down to 3,500 feet and in part on deductions from quantitative calculations in connection with torsion-balance surveys on salt domes. In the laboratory determination of the specific gravity of cores, a geologist was on the derrick floor when the core was recovered, took a sample of the core as nearly uncontaminated as possible, and determined the specific gravity before the sample had time to dry. In quantitative calculations on domes such as Belle Isle and Cote Blanche, in which the salt is very close to the surface and in which drilling has shown that the salt is normal in composition and does not contain an abnormal content of anhydrite, the observed gravity gradient definitely necessitates that the salt be regarded as of much higher density than the surrounding sediments, and in order to get a satisfactory fit of the calculated with the observed gradient profiles, it is necessary to assume a relative density of +0.3 for the salt if it is within a few feet of the surface and if the dome is near the coast. The gradient at a dome such as Belle Isle shows definitely

that the dome as a whole has positive relative density down to a depth of about 2,000 feet, and the amount of the cap rock present as determined by drilling is not sufficient wholly to account for this positive effect, and the salt down to a depth of 2,000 feet itself must have a faint positive relative density.   In the calculation in connection with any particular dome, the trial and error method is used to see whether the writer's assumed normal relative density or an assumption of less or greater relative density gives the best fit of the calculated with the observed values.   The South Liberty-Dayton dome was assumed to extend to a depth of 15,000 feet, to have a simple regular form with flanks flaring slightly with depth, and to have a normal relative density.   The gradient profile was then calculated by the writer's graphical chart method[1] with a chart especially designed for calculations of salt domes.   A calculated gradient profile was obtained which is shown by the dashed line with the crosses at the points for which calculations were made.

The observed gradient profile algebraically less the gradient profile of the South Liberty-Dayton dome will then be the resultant of A, C, D, and E, respectively, the gradient profile of the Esperson dome, the regional gradient, the profile of lesser structures, and of surficial irregularity and density.

The presence of a regional gradient can not be detected because the present survey does not cover a sufficiently wide area, but from the symmetry of the gradient profile, the guess would be justified that no considerable regional gradient is present.   It is possible, however, that a regional gradient of 1 or 2 E could be present and would not be noticed. From inspection of the gradient curve, it is impossible to detect the gradient effects of less pronounced structure, although a few slight irregularities seem to be present and seem not to be referable to the effects of the salt dome.   The quantitative calculations, however, separate approximately effects of different order; therefore, they tend to differentiate the effects of local structure, the effects of the large salt dome, and the effects of the more regional features.   The form of the gradient profile of a salt dome is not affected by the superimposition of a uniform regional gradient, and in calculation it would be impossible to get an agreement of fit of calculated with observed gradient profile by the moulding of the top of the salt dome.   It would be possible only by assuming some very much deeper or very much more widespread density differences.

[1] Donald C. Barton, "Calculations in the Interpretation of Observations by the Eötvös Torsion Balance," *Geophysical Prospecting, 1929*, (Amer. Inst. Min. Met. Eng., 1929), pp. 480-504.

The approximate position and form of the Esperson dome as shown in Figure 3 was calculated by the writer's graphical method. The known factors on which to base the assumptions for the calculations were the general form and symmetry of salt domes, the symmetry of the Esperson minimum, the data from drilling indicating that the dome did not extend to such a distance from the surface, and the normal density relations. By the trial and error method of calculations, a wide series of possible domes was calculated, and the dome with the cross section shown in Figure 3 was found to give the closest fit of calculated profile with observed profile. The sum of the calculated profiles for the Esperson and South Liberty-Dayton domes is shown by the profile of the short dashes with the solid circles at points at which calculations were made for the Esperson dome. The fit is not so good throughout the area between the two domes and seems very definitely to suggest that there is some extra heavy mass under station 4, lying with its center of gravity at a depth of 3,500 ± feet. From the deviation of the observed gradient profile from this calculated profile between stations 6 and 2, it would be impossible mathematically to get a closer fit by remodeling either the Esperson or the South Liberty-Dayton dome, and the lack of fit of the calculated with the observed profiles between stations 6 and 2 must be attributed to some variation of density in the sediments, at a depth of less than 5,000 feet and in a horizontal position between stations 3 and 5. The lack of fit of the calculated with the observed gradient profile northeast of station 6 may be due, however, to the fact that the observed gradient profile at the right of station 6 is based on very few stations and probably is not as accurate as the observed gradient profile at the left of station 6. The agreement in fit of calculated with observed gradient over the area of the profile suggests that no regional gradient is present.

The specific gravity of the salt at its several depths compared with the specific gravity of its sediments at the same depths is not known definitely and the problem is to arrange a variation which will produce appreciable differences in the size, and to a less extent in the shape and position, of the calculated dome. The calculated series of domes corresponding with a series of assumptions in regard to the relative density are in general more or less concentric and similar in form, with their centers of gravity at about the same position.

The top of the dome necessarily can be calculated only very indefinitely. The relative density of the salt above 7,000 or 8,000 feet is very small and is approaching zero at a depth of 3,000 - 5,000 feet. Small variations in the conformation of the top of the salt mass, therefore,

produce no appreciable effect on the gradient at the surface, and it is
practically impossible to tell whether or not the top of the salt core lies
at a depth of 6,000 or 7,000 feet, and the difference between a depth of
6,000 and 8,000 feet in the depth to the top of the salt core produces
only a very small difference in the calculated profile. The fit of the cal-
culated with the observed gradient profile seemed to be a little closer
if the top of the salt was placed at 6,000 feet rather than at 8,000 feet,
and in the section of Figure 3 the salt mass is shown rising to a depth of
6,000 feet below the surface, but it will be in no way surprising if drilling
shows its depth to be much greater.

The depth to the bottom of the salt mass also is given only very in-
definitely by the calculations. Because of the law of the variation of the
effect according to the inverse cube of the distance, the effect of a unit
mass at 15,000 feet is very much less than the effect of a unit mass at
7,500 feet. The depth to the bottom of the salt dome could be 16,000
or 17,000 feet as well as 15,000 feet. The depth might also be 14,000
feet, but it can not be much less or it would be impossible to get a satis-
factory fit of the calculated with the observed gradient profiles. A ten-
tative study was made with the assumption that the salt mass extended
down to a depth of 20,000 feet; but on the basis of the present assump-
tions in regard to the relative density compared with the surrounding
sediments, no satisfactory fit of calculated with observed gradient pro-
file could be obtained. The writer and his colleagues have not had time
to continue these studies and it is possible that by the use of a different
series of assumptions in regard to the relative density, a satisfactory fit
of calculated with observed profiles could be obtained. The present
suggestion, however, is that the depth to the base of the salt dome is
nearer 15,000 than 20,000 feet.

The suggestion has been made, more particularly in regard to the
Roumanian domes, that many salt domes may pinch out in depth and
have the form of an inverted pear with the stem downward. Above the
depth of 15,000 feet, such a cross section is entirely impossible for the
Esperson and South Liberty-Dayton domes. It would be entirely im-
possible to get a satisfactory fit of the calculated with the observed gra-
dient profiles on the basis of any suggested assumptions in regard to the
form of the two domes.

Indefiniteness in the calculation of the dome is due also to the in-
completeness of the torsion-balance data on which the calculations have
to be made. The probable error of the torsion-balance observations in
this area is of the magnitude of 1-3 Eötvös units with any azimuth.

The gradient profile west of station 6 is a smoothed profile drawn on a basis of a very considerable number of stations; therefore, it is probably accurate within ± 1 Eötvös unit, and possibly within ± ½ Eötvös unit, but within those limits of error, a considerable series of gradient profiles can be drawn and a slightly different dome will correspond respectively with each profile. The gradient profile northeast (right) of station 6 (Fig. 3) is based on a very few stations; therefore, the probable error of the smoothed observed gradient profile is considerably larger and a considerably greater number of more widely divergent equally probable profiles can be drawn. Errors in this part of the curve will cause a greater indefiniteness in the calculation of the base of the two domes than in the form and position of the upper part of the Esperson dome.

SHIFT OF CENTER OF MINIMUM

The shift of the center of the Esperson minimum away from the center of uplift may be caused by four factors: (1) asymmetry of the dome, (2) regional gradient, (3) a spine of salt rising into a neutral zone, and (4) local anomalies of gravity at shallow depths. Asymmetry in a structure will produce a horizontal shift in the position of the center of the gravity anomaly away from the position of the crest of a structure. Coincidence between the respective position of the crest of a structure and the gravity anomaly produced by the structure exists only if the structure is symmetric. If the structure is asymmetric, the center of the gravity anomaly is shifted horizontally toward the position of the center of gravity of the structure. If the asymmetry of the structure is pronounced, the horizontal position of the gravity anomaly lies a considerable distance down the gentle side of the structure.

A regional gradient causes a shift of the center of the gravity minimum down the regional gradient, that is, in the direction opposite to that in which the gradient arrows of the regional gradient are flying. If the gradient 1 mile north and 1 mile south of the center of a minimum is 5 E and if a regional gradient of 5 E north is superimposed, the observed gradient 1 mile north of the center of the minimum will be $5+5 = 10$ E and 1 mile south of the center of the minimum will be $5-5=0$ E, and the apparent center of the minimum will have been shifted to a point 1 mile south of the true center of the minimum. The regional gradient may be either a true regional gradient, which is fairly uniform over the whole area, or it may be the sum of the effects of the major structural features surrounding the structure which is being analyzed, or it may be the sum of a truly regional gradient and of the effects of

such surrounding major structures. The regional gradient at the Esper-
son dome can be seen to be composed of the effects of the South Liberty-
Dayton, the Moss Bluff, the Lost Lake, and the Barber's Hill salt domes,
and probably the North Dayton salt dome, and may also contain a truly
regional gradient, but the presence of the truly regional gradient can
not be deduced on the basis of the rather limited area of the present
survey.

A spine of salt projecting into the neutral zone in which the salt has
the same density as the surrounding sediments would cause a very great
shift of the center of the minimum from the position of the center of up-
lift in the upper salt beds. At Esperson it is possible that the neutral
zone extends to a depth of 7,000 feet. If the short spine of salt rose from
7,000 to 5,000 feet, the presence of the salt in that spine could not be
detected by any gravitational method, but the spine would be the crest
of the salt dome and would control the deformation of the super-salt
beds, and also control the accumulation of oil.

Local anomalies of density in the super-salt sediments may produce
an apparent shift of the center of the minimum if the magnitude of its
gravity anomaly is considerable. If a local anomaly similar in magnitude
to the lack of fit of the calculated with the observed profiles between sta-
tions 6 and 2 (Fig. 3) occurred from station 4 to station 6 with the
center at station 7, and the gradient profile of this anomaly were super-
imposed on the gradient profile of the Esperson dome, the apparent
center of the Esperson minimum would be shifted about $\frac{1}{2}$ mile west
from its present position and the shift would have no relation to the salt
dome.

INDEFINITENESS IN INDICATION OF DOME

An indefiniteness is present in the indication of the position of the
crest and in the indication of the depth of very deep salt domes by the
torsion-balance method. A torsion-balance survey may indicate def-
initely the presence of a very deep salt dome, but it may be impossible
to determine the position of the center of uplift from the torsion-balance
survey with sufficient accuracy for the location of test wells. The in-
definiteness in part depends on the method of the interpretation and in
part on the amount of data available. The first and simplest but not the
most accurate method of interpretation is to assume that the center of
the minimum marks the center of the dome, but on account of the factors
which may cause a shift of the center of the maximum, the observed
center of the minimum commonly does not coincide in position with the

center of the dome. If the torsion-balance survey includes a large area, it may be possible to make an approximate determination of the regional gradient and to subtract the regional effects from the observed effects, thus obtaining a first approximation to the true position of the center of the minimum. This second method gives a better determination of the center of the dome, but that determination is subject to the uncertainties consequent upon the facts: (1) that the center of a gravity anomaly does not necessarily coincide with the anomalous mass which produces it, (2) that the very small value of the relative density of the upper part of the salt causes the gradient effect produced by the upper part of the salt to be very small, (3) that certain local anomalies can not be eliminated by inspection, and (4) that a salt spine in the neutral zone will produce no gravitational effect. A third, and theoretically the most accurate, method of determining the position of the dome is to calculate its probable form and position. The effects of the regional gradient and of local anomalies largely fall out in such calculations. The calculations may be made, however, only if fairly good and fairly long profiles are available across the dome. But the form and position of a dome determined by such calculations in no way show the location of the center of uplift in which the oil man is primarily interested. Normally torsion-balance surveys for deep domes should be regarded as reconnaissance surveys which may definitely locate the presence of a deep dome and its approximate position, but will not give an accurate determination of the crest of the dome. The torsion-balance survey normally should be supplemented by a seismic survey to countour the seismic horizons in the super-salt formation, thus determining the center of uplift.

An additional uncertainty in regard to the deep salt domes indicated by the torsion balance lies in the absence of indication of the presence or absence of uplift in the super-salt beds.

Geologically, it is probable that the uplift on certain domes may have ceased very remotely, in early Tertiary time. The lack of deformation of Pleistocene beds above some domes indicates the absence of appreciable uplift of those domes since some time in the Pleistocene. The large mounds of the Five Islands, Damon Mound, Davis Hill, suggest very definitely uplift within the very recent geologic past. Geologically, there seems to be no reason why uplift on some of the very deep domes may not have ceased early in Eocene time. The late Eocene and post-Eocene beds above the salt, therefore, would show no deformation, would not offer favorable structure for the accumulation of oil, and would not allow the drill to confirm the presence of the dome until the drilling was carried into the lower Eocene. However, the gravity anom-

alies produced by such domes may be entirely identical with the anomalies which would be produced by the domes if they had been uplifted 500 feet within post-Pleistocene time; and post-Pleistocene uplift of the salt core to the extent of 500 feet probably would provide exceptionally favorable structural conditions for the accumulation of oil.

GRAVITY MAXIMA

Gravity maxima, one type of which is represented by the maxima of the present survey, are present in three or perhaps four types in the Gulf Coast salt-dome area: (1) salt-dome maxima, (2) inter-dome maxima, (3) structural maxima, and (4) sedimentary maxima.

The salt-dome maximum is the characteristic gravity anomaly produced by the upper part of a shallow salt dome. The maximum in the main is the effect of the cap rock, but in part also is the effect of the salt mass itself in exceptionally shallow domes near the coast. The maximum has a slightly larger diameter than the top of the dome, a relatively flat top, and relatively large gradients in a relatively narrow zone immediately above the flank of the cap. The magnitude of the gradients in the zone of maximum gradient commonly ranges from 10 to 30 E and, less commonly, 40 to 150 E.

The inter-dome maximum is of the type shown in the present survey. It may be thought of as being produced by the interference of two large minima, or as being the gravity anomaly produced by the prism of sediments between the salt domes. The maximum tends to have rather long, gentle slopes without the relatively narrow zone of relatively large gradients which characterize the salt-dome maxima. The magnitude of the gradient commonly ranges from 3 to 10 E. Whereas the salt dome maxima are circular to sub-circular, the inter-dome maxima more commonly are somewhat irregular in plan and are elongated. If the maximum is produced by the interference of only two minima, it will take the form of a ridge or of two ridges, but if three minima form an approximately equilateral triangle, the maximum may be fairly symmetrical. The difference between the inter-dome maxima and a salt-dome maximum was not recognized in the early days of torsion-balance work. The inter-dome maxima were recognized as not being characteristic salt-dome anomalies, but it was hoped that they might be anomalies produced by moderately deep domes. A series of wells was drilled on them, with entirely negative results, as a maximum of this type is the most unfavorable location in which to expect to find oil in the Gulf Coast region.

Maxima produced by structural domes probably are present in the Gulf Coast region, but are rare. The writer has seen a torsion-balance map of one anomaly which seems to him to indicate non-salt-dome structural doming of some type. It is a much more definite maximum than the characteristic inter-dome maxima and no salt domes are known either from drilling or geophysics which would cause an inter-dome maximum at that place. The presence of structural uplift has been confirmed by seismic work, and there is some paleontological evidence which seems to indicate the presence of the uplift.

Maxima and minima due to initial inhomogeneity in the density of the sediments theoretically seem probable. Such anomalies should be more irregular than the other types of anomalies, and in general should be smaller areally. A common former interpretation of any maximum which was drilled unsuccessfully was that it was the effect of a "gravity bed," but now many of those maxima are known definitely to be of the inter-dome type produced by the interference of two or more salt-dome minima. "Sedimentary" maxima may be present. Several maxima have been seen by the writer which he would classify as of that type. A minimum of this type was mapped at Cote Blanche, where there is a thickening of the soft light surface clays from 50 to several hundred feet in thickness immediately above the crest of the salt core.
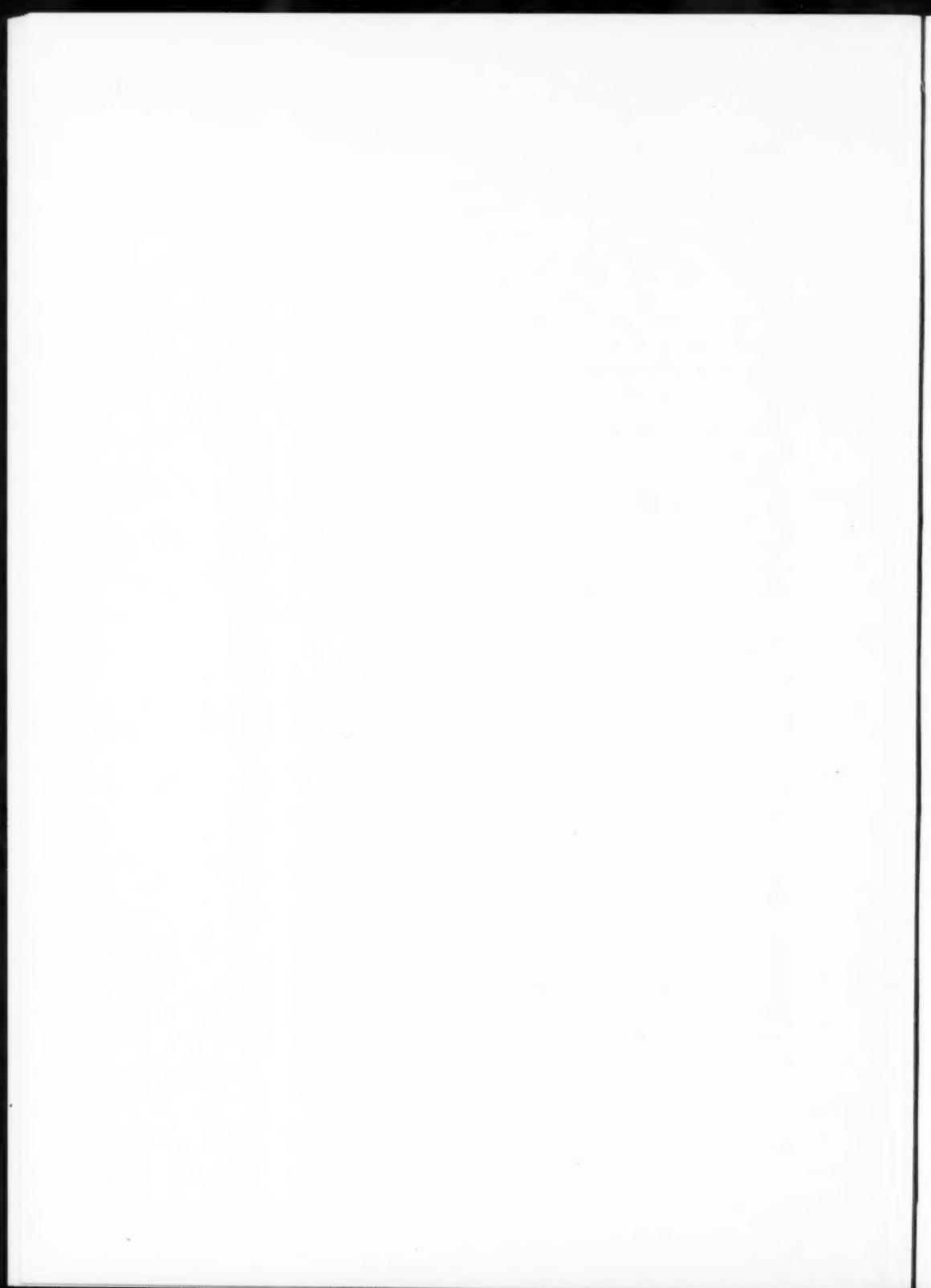
ELECTRICAL PROSPECTING FOR OIL STRUCTURE[1]

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ABSTRACT

Electrical prospecting methods were originally developed for the purpose of find-ing ore. Only recently have electrical methods been applied to oil prospecting. Some investigators assert that oil can be located directly as an insulator by electrical methods, but this is believed to be possible only under extremely favorable conditions, which occur in very few places.

Both potential and electromagnetic methods have recently been applied to struc-tural studies. Electromagnetic methods, so far as developed at present, are believed to have broader applicability because of greater depth penetration.

The Swedish electrical methods for structural studies are described, and the pos-sible applications discussed. The conclusion is that these methods have broad applica-tion and that they are particularly suitable for detail work, especially in faulted re-gions.

Results of electrical surveys in the salt-dome district of Texas and Louisiana, the Balcones fault zone in central Texas, and the West Texas Permian basin are presented and are compared with results of drilling. Most of the electrical pictures agree well with the geological.

A party of two or three engineers and twelve or fifteen helpers can survey an area of 1-6 square kilometers a day. The depth reached generally ranges from 500 to 1,500 feet.

GENERAL

Although the application of geo-electrical methods to prospecting for oil is only a few years old, electrical prospecting methods have al-ready been highly developed.

As is commonly known, oil is an insulator, that is, it does not con-duct electricity; an oil deposit, therefore, differs in regard to electrical conductivity from the surroundings, which ordinarily are more or less conductive. Therefore, if the surroundings of an oil deposit are homo-geneous in regard to their electrical conductivity, there is the theoretical possibility of locating oil directly by electrical methods.

However, all oil deposits are accompanied by salt water, which is a good conductor for electricity, and above an oil-bearing stratum there

[1] Read before the Association at the New Orleans meeting, March 21, 1930. Man-uscript received by the editor, March 3, 1930.

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are ordinarily many salt water-bearing beds, many with good electrical conductivity. These conducting beds may produce strong electrical effects, which may obscure and mask the effects possibly produced by the deeper oil-bearing bed. All attempts to locate oil deposits directly by electrical methods have, therefore, failed, and it now seems that further attempts for this purpose are justifiable only in fields with very shallow oil.

However, the widely varying conductivity of the beds above an oil deposit offers a possibility of using electrical methods indirectly in searching for oil. If, for example, a sedimentary bed at a depth of a few hundred meters has a higher electrical conductivity than any of the strata above it, the depth to this key bed can be determined electrically from the surface at any point in a specified field; thus, the configuration or structure of the sedimentary beds can be studied.

METHODS AND THEIR APPLICATION

The electrical methods used for mapping structure in the search for oil can be classified in the same way as the electrical prospecting methods used in the mining industry. There are only two such methods of any importance which have become generally known. One is an entirely galvanical method; the other is entirely inductive or electromagnetic.

The first method, which supplies current to the ground galvanically and measures the electric field of the ground current galvanically, is generally termed the resistivity method. The Gish-Rooney process, which is the most widely known adaptation of this method, uses a system of four ground contacts placed with equal spacing on a straight line. An electrical current, the strength of which is measured, is sent through the ground between the two extreme points, and the resulting potential difference between the two intermediate points is measured. The data thus obtained, combined in a simple formula with the distance between the electrodes, show the resistivity of the block of ground in the vicinity of the electrode system. The resistivity thus measured is an average value, composed almost wholly of the resistivities close to the electrodes, and influenced only in a degree by conditions farther away from the electrode system. Resistivities at a subsurface depth greater than the distance between the extreme electrodes have almost no influence on the readings. Thus, the electrode spacing determines the depth which can be reached by the investigation; by increasing the distance between the electrodes, deeper and deeper blocks of ground can be reached by the measurements. When the results obtained from such a series of measure-

ments are compared with the electrode spacing used, it is possible to determine whether a change in resistivity has occurred, and if so, to determine the depth at which it occurred.

This method, which has several variations in regard to configuration of the electrode system, the kind of current used, et cetera, has been applied in determining the depth of soil in erosional valleys (for dam sites), the depth of ground-water levels, and the location of faults and shallow salt domes. Excellent results have been obtained, especially by determining the depth of bed rock under overburden. Two domes in Roumania, in 1923, and two salt domes in Alsace, in 1926, were discovered by the Schlumberger resistivity method.

However, in prospecting for structures associated with oil deposits, the resistivity methods seem to be at a disadvantage, because they are ordinarily restricted to the study of geologic conditions at comparatively shallow depths. According to the theory for the potential distribution on the surface caused by subterranean layers of differing resistivity, changes in resistivity of a few hundred per cent produce effects of the same order (probably half the magnitude) as the effects produced by insulating or metallically conducting layers. Inasmuch as all the changes in resistivity of the sedimentary beds, encountered from the surface down to a comparatively shallow depth, influence the electric field at the surface, the total effect of these many influences tends to overshadow and obscure the effect expected from a pronounced change in resistivity at a greater depth.

The area most thoroughly investigated with regard to surface conductivity, with which the writer is familiar, is the Balcones fault zone in central Texas. Figure 1 shows typical results in this area, indicating the average specific conductivity to a depth of 6 meters, determined according to the Gish-Rooney principle at every 200 meters on the profile. The ratio between these surface conductivities in points 200 meters apart is shown on the profiles. Inasmuch as the average dip is 4-5 per cent, a horizontal distance of 200 meters corresponds with a depth of 8-10 meters; it is apparent that great conductivity changes occur at comparatively shallow depths overshadowing effects from greater depths.

Notwithstanding this limitation, the resistivity method has been proved of great value in many oil fields. Such a study of geologic conditions at shallow depths can be very useful. It has been possible, for example, in many places to determine the contact between different formations more quickly and accurately by this method than by geological observations, although the beds are exposed. Also by the re-
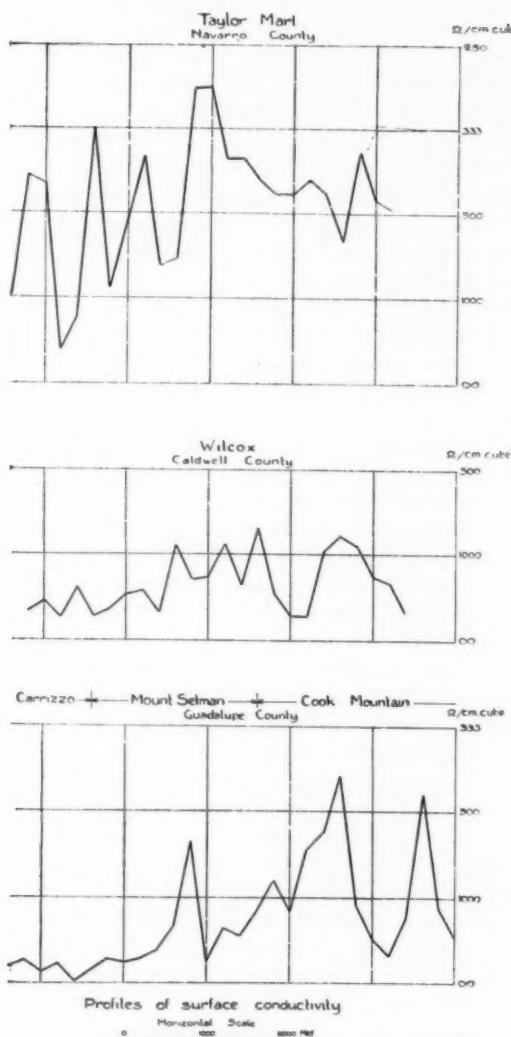
FIG. 1.—Profiles showing variation of surface conductivity in the Balcones fault zone.

sistivity method, domal structure has been outlined by the "equi-resistivity lines" obtained by connecting points of equal resistivity of the shallow surface beds. This, however, can not well be applied every-where, because ordinarily the resistivity of the surface beds may not be related to the subsurface structure.

The second of the two methods most widely applied in electrical prospecting for oil structure is the electromagnetic method developed by the engineers of Aktiebolaget Elektrisk Malmletning and the Swedish American Prospecting Corporation. By this process electrical currents are caused to flow in the conducting sedimentary beds by electromag-netic induction, and the electromagnetic field of these subsurface currents is studied at the surface by suitable measuring arrangements.

The procedure of the field work is here outlined. A long, insulated copper cable is laid on the ground, generally in the shape of a large rectangle. An alternating electric current of moderate frequency is sent through this cable, and the resulting electromagnetic field is meas-ured on the ground along transverse profiles which cross the cable at regular intervals. Generally the electromagnetic field is measured on each transverse line at several different distances from the cable, and both the horizontal and vertical components of the field are measured in regard to amplitude and phase. The measuring apparatus consists of a search coil of copper wire of convenient size and a compensating arrangement, by means of which the electromotoric force induced in the search coil is measured. The measuring arrangement is so calibrated that it measures the field vectors in semi-absolute units, that is, in micro-gauss (a millionth part of a gauss) per ampere of primary current in the cable. The vectors measured are expressed by their real (in-phase) and imaginary parts, and the readings obtained are thus referred to a cartesian coördinate system, as shown in Figure 2.

Figure 2 shows two curves from a vector diagram for the vertical electromagnetic field at the surface, at a distance of 200 meters from the primary cable. The vector diagram is constructed from theoretical cal-culations of the electromagnetic field from the currents induced in a con-ducting sheet of large horizontal dimensions, by an alternating current in a long straight cable, stretched parallel with the surface of the con-ducting sheet. The theory and the elaborate mathematical formulas on which these calculations were founded have been checked by labor-atory experiments and tests in the field.

The abscissa axis, designated the real component axis in the figure, represents the direction of field vectors which are in phase with the
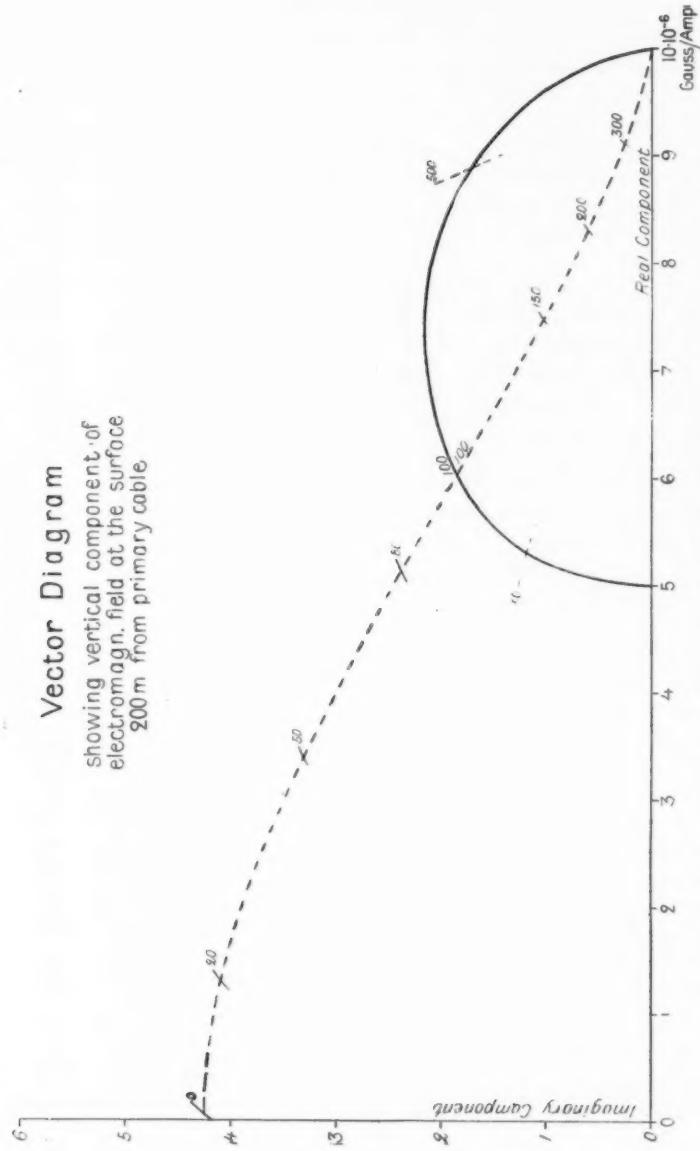
Fig. 2.—Vertical component of electromagnetic field at a point 200 meters from primary cable.

primary current. The ordinate axis, termed the imaginary component axis, represents the direction of field vectors which have a phase differing ¼ period, or 90°, from the primary phase.

The dotted curve is the locus for a point representing the field from a horizontal conducting sheet of certain electrical properties. If this layer is at the surface, the reading obtained is represented by the point marked o on the figure; if the layer is at a depth of 100 meters, the reading falls at the point marked 100 on the dotted curve, et cetera.

The solid curve in the figure is the locus for a point representing the field from a horizontal conducting layer at a depth of 100 meters. If the conductivity or thickness of a layer at this depth decreases, the point representing the field moves along the solid curve toward the higher numbers on the curve, and vice versa.

It is evident from this diagram, that if only one conducting layer is present at a certain depth under the surface, both the depth and the electrical properties of this layer can be determined by the method described, by measuring the vertical component of the electromagnetic field at only one point. Inasmuch as there are similar diagrams for the horizontal field component, the same result can be obtained by measuring, at one point at the surface, the horizontal electromagnetic field.

In order to determine depths and electrical characteristics of several beds, it is ordinarily necessary to take readings of both the vertical and the horizontal field components at several points on the transverse lines, at different distances from the cable. The theoretical problem of calculating the electromagnetic field caused by conducting beds one below another has been solved, and there are vector diagrams similar to those already mentioned, which include the compound effect of several layers. By the standard field procedure, as already described, the number of data obtained is generally two or three times more than necessary for solving the number of unknown factors in the problem. There is, therefore, always ample material from the electrical survey to enable one to assign the electrical effects observed to the several different layers and to determine the depths and characteristics of all the beds. Although the exact solution of this problem for each transverse line surveyed is very laborious and time-wasting, field experience has shown that conditions are generally similar in large areas, thus enabling an experienced operator to simplify the interpretation.

POSSIBILITIES FOR APPLICATION

The application of the electromagnetic method for structural studies presupposes the presence in the sedimentary series of layers or beds with

considerably higher conductivity than the overlying rocks. The method
is not sensitive to the minor changes in conductivity of the different beds,
already mentioned as a serious handicap to the resistivity method in
regard to its ability to reach sufficient depths. On the contrary, one
may question whether there is always a probability of the presence of
the conducting key beds, without which the method can not be applied.

To this one might reply that the conducting beds have been present
at suitable depths wherever the method has been applied in oil fields.
However, discussion of the geological reasons for this fact and of the
factors determining the conductivity of rocks may also be interesting.

All rocks are porous to some extent, and the pores are partly or
entirely filled with water, oil, and gas. Dry rock-minerals, with the
exception of the ore minerals of metallic luster, can, in this connection,
be considered non-conducting. The electrical conductivity of a rock is,
therefore, practically determined by two factors: (1) percentage volume
(V) of water in the rock, and (2) specific resistance (R) of the water in
the rock pores.

The resistivity of a certain rock is PR where P is a resistance factor
depending on the percentage of water volume (V). The relation between
P and V, as found by theoretical calculations confirmed by experimental
investigations, is given in Figure 3. If a rock contains 20 per cent water,
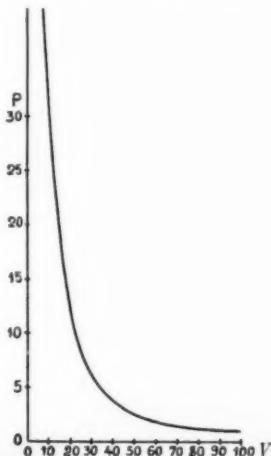
FIG. 3.—Relation between resistance factor (P) and percentile volume (V) of
water in rocks.

the figure shows the resistance factor to be 11, and if the resistivity (R) of the water is 1,000 ohms/cm³, the resistivity of the rock will be 11 × 1,000 = 11,000 ohms/cm³.

The percentage volume of water in a rock can not, of course, be larger than the total pore volume. Many geologists believe that the pores in rocks beneath the ground-water level are generally entirely filled with water. The electrical resistivity of such rocks is, therefore, determined by pore volume of the rocks and resistivity of the water filling the pores.

The average pore volume and, therefore, the water content for different rock types are shown in Table I, after Blumer's "*Die Erdöl-lagerstätten.*"

TABLE I

Rock	Pore Volume	Per Cent
Fine-grained granite	0.05	0.45
Coarse-grained granite	0.36	0.86
Syenite	0.50	0.60
Porphyry	0.40	0.60
Sandstone	4.00	27.00
Dolomite	1.50	22.00
Limestone	1.00	17.00
"Loess"	41.00	46.00
Sand	24.00	42.00
Clay	30.00	50.00

The electrical conductivity of waters has not yet been much studied, but chemical analyses of waters, from which the specific electro-resistance of the waters can be calculated, are more generally available. The accurate calculation is rather complicated, but it can be stated accurately enough for practical purposes that the specific resistance of a natural water is generally determined by its content of chlorine. The relation between chlorine content and specific resistance is shown in Figure 4.

For present purposes, the waters may be classified as follows: (1) surface waters, above the ground-water level; (2) ground waters; and (3) subsurface waters, beneath the ground waters.

Inasmuch as the chemical composition and the specific resistance of these waters varies tremendously, it is difficult to give general figures. In most areas the surface waters are purer than ground waters, and many of the subsurface waters are concentrated solutions. The magnitude of the specific resistance of surface and ground waters in pre-Cambrian regions is 3,000-30,000 ohms/cm³; in areas of young sediments, 200-2,000 ohms/cm³. Many subsurface waters show a specific resistance of only 10-100 ohms/cm³.
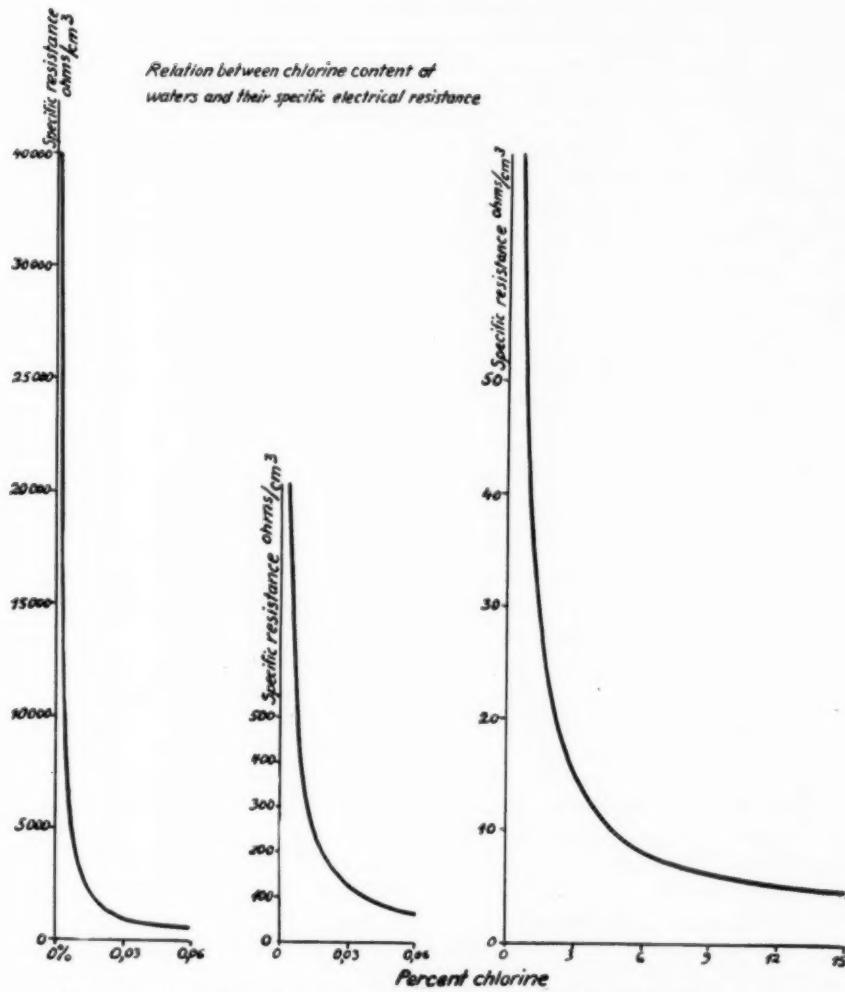
FIG. 4.—Relation between chlorine content of waters and their specific electrical resistance.

By the use of these resistivities and the pore volumes shown in Table I, Table II has been prepared, showing the magnitude of the resistivity of different rocks.

TABLE II

SPECIFIC RESISTANCE (OHMS/CM³)

Rock	Pores Filled with Surface or Ground Water	Pores Filled with Salt Water
Limestone and sandstone	100,000-1,000,000	500-4,000
Sand and clay	40,000- 400,000	200-2,000
Marl, "loess"	2,000- 20,000	20- 200

From Table II is it evident that the variations in electrical conductivity of sedimentary beds are great enough to make probable the presence in every locality of some beds with much higher conductivity than all of the beds above them.

Another question that might be asked is whether the configuration of the conducting layers mapped by this electrical method can be expected to represent, in every place, the geologic structure.

This can not be expected for conducting sheets encountered at very shallow depths. For example, the electrical conductivity of layers at the very surface is large enough to influence geo-electrical readings materially. Clayey surface beds, with large pore volume and large capacity for retaining water, may show very strong influence on the electrical readings. The configuration of these beds, of course, is not generally related to the geologic structure.

The ground-water level also commonly represents a conducting surface that has a certain influence on the geo-electrical readings. The configuration of the ground-water level is determined, as Figure 5 schematically indicates, both by the geological structure of the water-bearing beds and by the topography of the surface. Therefore, a mapping of this configuration, though indicating the geological structure, gives no true structural picture.

Below the ground-water level, however, water of a certain concentration seems everywhere to follow a certain bed, thus making this bed a conducting sheet, the configuration of which gives an accurate picture of the geologic structure. This parallelism between certain waters and the sedimentary beds is exemplified in several geological sections given by A. C. Veatch in his important paper, "Water Conditions in Northern
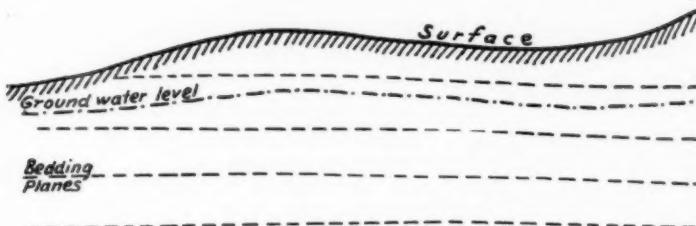
Fig. 5.—Diagram showing that ground-water level is more nearly parallel with the surface than with the structure.

Louisiana, Southern Arkansas, and Adjacent Regions," published in the *Louisiana Geological Survey Report for 1905*. H. E. Minor, in his paper on "Chemical Relations of Salt-Dome Waters," published in 1926 by *The American Association of Petroleum Geologists*, points out that in the Gulf Coast fields a structure map based on a water of specified concentration is, as a matter of fact, more reliable than a structure map based on the ordinary stratigraphical identification of different beds, inasmuch as the stratigraphical correlation of beds is extremely difficult because of abrupt thickening and thinning, whereas the salt content of the water for a producing horizon remains almost constant, although the sands themselves are not continuous.

Structural mapping by electrical methods should, therefore, be confined to the deepest conducting layers possible to reach.

The conductivity of the surface beds or the beds at the ground-water level in a certain locality may be so high that it is impossible to penetrate electrically to the beds beneath, because of the screening effect of the upper beds. Inasmuch as this screening effect can be reduced by the use of lower frequency of the current, it is generally possible to penetrate to greater depths through a shallow conducting layer of comparatively large influence on the geo-electrical readings.

PRACTICAL RESULTS

The Swedish electrical methods for mapping structures have been applied in the United States during the last three years in Texas, Louisiana, and California. In Texas and Louisiana investigations have been made in the salt dome district of the Gulf Coast, in the Balcones fault zone in central Texas, and in the West Texas Permian basin.

SALT-DOME DISTRICT

The success of seismic methods in the salt-dome district of the Gulf Coast is well known. Several known salt domes have been surveyed electrically and the dome of each has been indicated. The possibility of locating salt domes by electrical methods is thus proved. As a matter of fact, salt-dome indications have been found outside of known domes in the surveys, but the corresponding indications have not yet been drilled. Generally, it will be cheaper to make the reconnaissance survey for salt domes on the Gulf Coast by seismic methods, but when a salt dome has been found, it can be advantageously mapped in detail by electrical methods. Experience indicates that the mapping of faults related to the domes, generally impossible by any other geophysical method, is entirely feasible by the electrical method.

Figures 6 and 7 show electrical surveys of two salt domes in Texas. The electrical results are represented by contours on the top of the mapped conducting bed, constructed from the depth determinations at the points shown. The "salt indications" represent areas where the depths obtained are infinite, indicating the conducting bed to be absent, because of the non-conducting salt mass. Near these salt indications the beds generally show domal structure and are faulted according to the electrical survey, as in the two examples shown. Comparison of the electrical results with the well data shown in Figures 6 and 7 indicates that the salt domes have been very accurately outlined by the electrical survey. On the side of the dome shown in Figure 7, some oil was produced. Two wells, No. 18 and No. 19, have been drilled outside of the proper dome structure, close to the fault indication *C-D*. Well 18 has been a producer for more than a year, and it is reasonable to connect the production with the fault, which was found by the electrical survey.

BALCONES FAULT ZONE

The most important problem of the economic geology of the Balcones fault zone is that of mapping faults. This mapping must be done very accurately in order to find possible closures, because a slight bend in the strike of the fault may be sufficient to produce the closure, as Figure 8 indicates. An area of approximately 4,000 square kilometers (1,500 square miles) in the Balcones fault zone has been investigated electrically, and many indications of faults have been found. Thirty-eight of the fault indications have been further investigated by drilling, and thirty-one indications were proved to be faults. In five places the wells did not give conclusive proof, and in two places the electrical in-
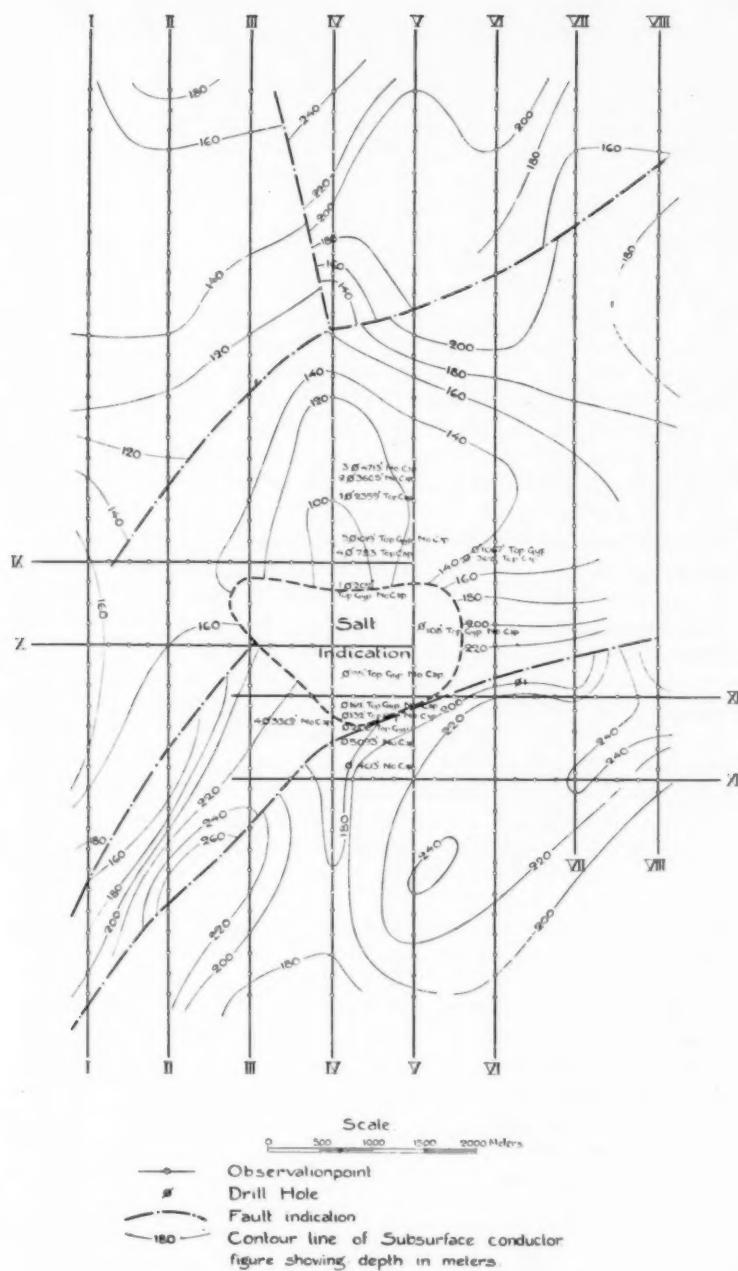
FIG. 6.—Electrical survey of Hawkinsville salt dome.
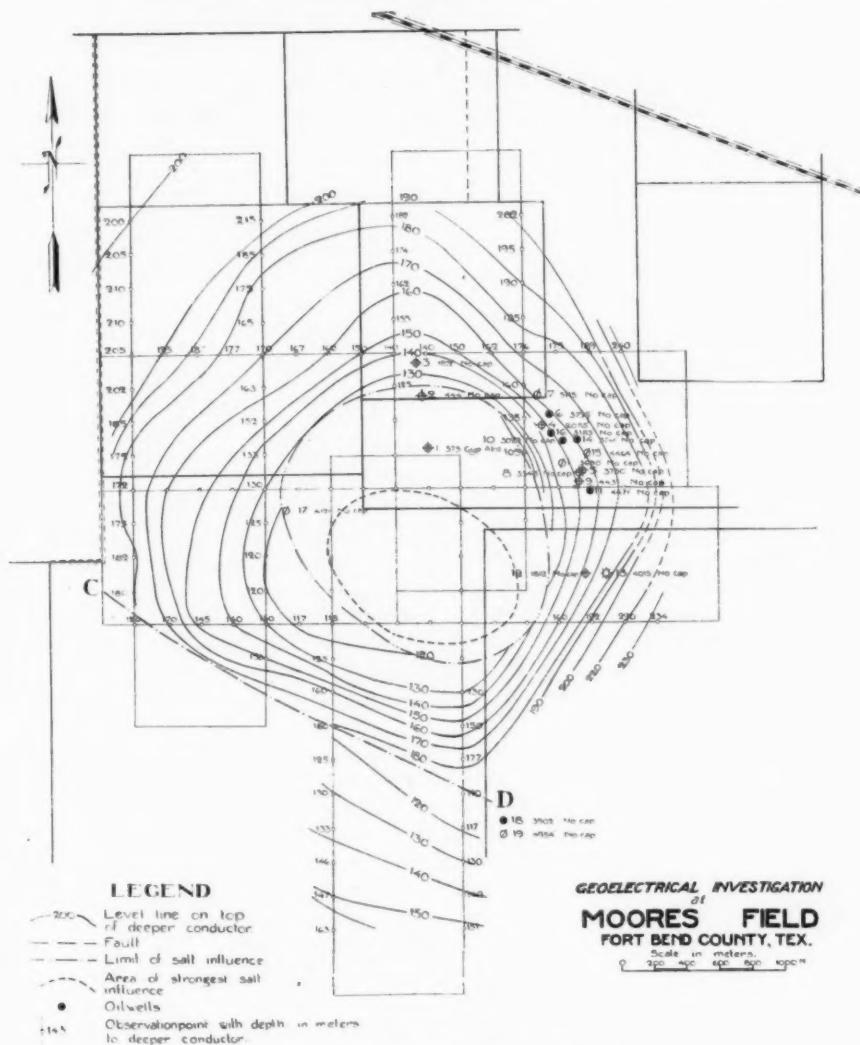
FIG. 7.—Electrical survey of Orchard salt dome.
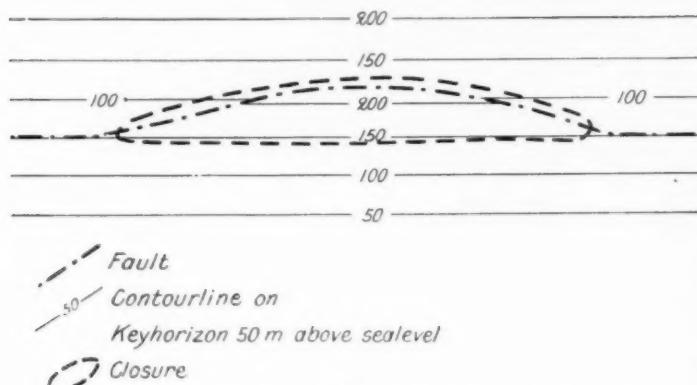
FIG. 8.—Diagram showing that a slight bend of a fault may produce a closure.

dications which were proved not to correspond with faults were probably due to a pinching-out of the conducting beds.

Figure 9 shows in detail the electrical results obtained. The main fault indication *A-B* seems to indicate a closure (compare Fig. 8). This fault, which was mapped in approximately one month, is parallel with the producing area, as the map shows. When the electrical survey began, only one well, a wildcat, was producing, and the configuration of the fault was unknown. Later drilling proved the electrical picture correct, the mapped conducting bed being practically parallel with the key beds (Austin chalk, Edwards limestone) encountered in the wells.

WEST TEXAS

In the Permian basin of West Texas the problem has been that of locating and mapping anticlines and other important structural features. Figure 10 shows the result of an electrical survey in the northern part of the Yates field in West Texas, compared with later drilling. The figure shows the contours on the top of the electrically mapped conducting bed, together with available well information, from which have been constructed subsurface contours on the top of the producing limestone. In a comparison of these geological contours with the electrical, the general parallelism is striking, the crest of the geological anticline coinciding with the crest of the electrical anticline, and strike and dip according to the electrical survey agreeing very well with actual strike and dip, except in some details in the southwestern part of the surveyed
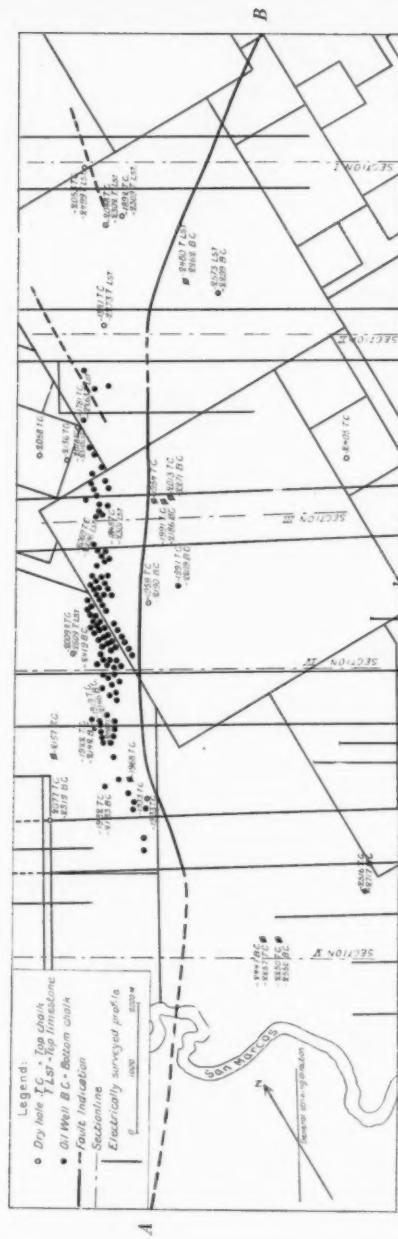
Fig. 9.—Electrical map of the Salt Flat (Bruner) fault.
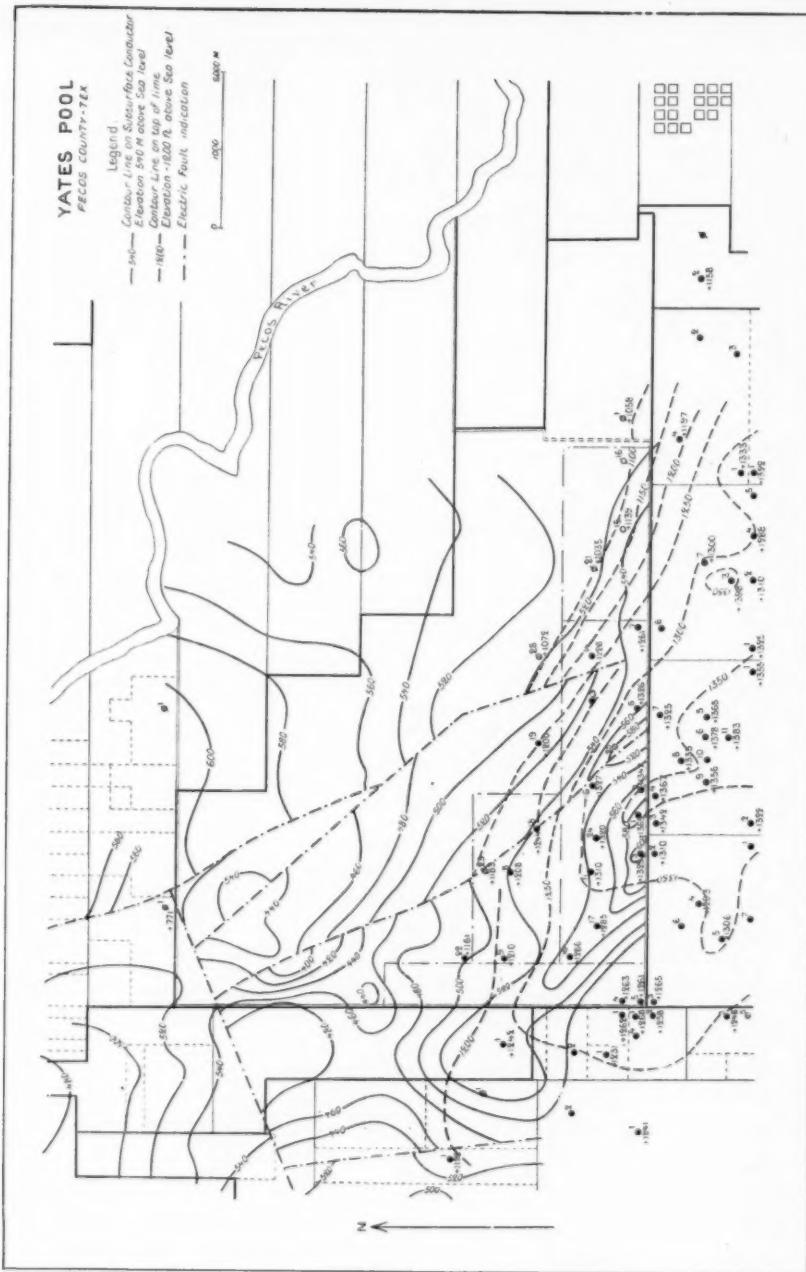
FIG. 10.—Comparison between electrical results and geological structure in Yates field.

area. There is reason to believe that this disagreement is due to inaccurate correction for very rough topography, for which there was little experience for guidance. Later experience has improved the topographical corrections.

The electrical survey showed three northwest-southeast fault indications in the drilled area. The wells permit the coutours at the eastern and middle faults to be drawn as indicated, proving the possibility that the electrical indications correspond with actual faults. At the western fault indicated in Figure 10, too few wells exist to make any certain conclusions possible.

SPEED OF WORK AND DEPTH REACHED

For the conditions in Texas and California it has generally been found sufficient to survey profiles ½-1 mile apart, and to determine the depth to the subsurface conducting beds at points 200 meters apart along the profiles. Where subsurface conditions are very nearly uniform, this interval in reconnaissance work may be increased to 400 or to as much as 500 meters. In open, flat country 15 points can be surveyed in one day by one crew, consisting of two or three engineers and twelve or fifteen helpers. In country with rugged topography or dense bush five points may be surveyed daily. Consequently, the area surveyed in one day ranges from 6 square kilometers to ¾ square kilometer (1,600 to 200 acres). Thus the cost per acre is from $0.20 to $1.60.

At the present stage of development of the technique, the electrical picture is generally obtained at depths ranging from 500 to 1,500 feet below the surface.
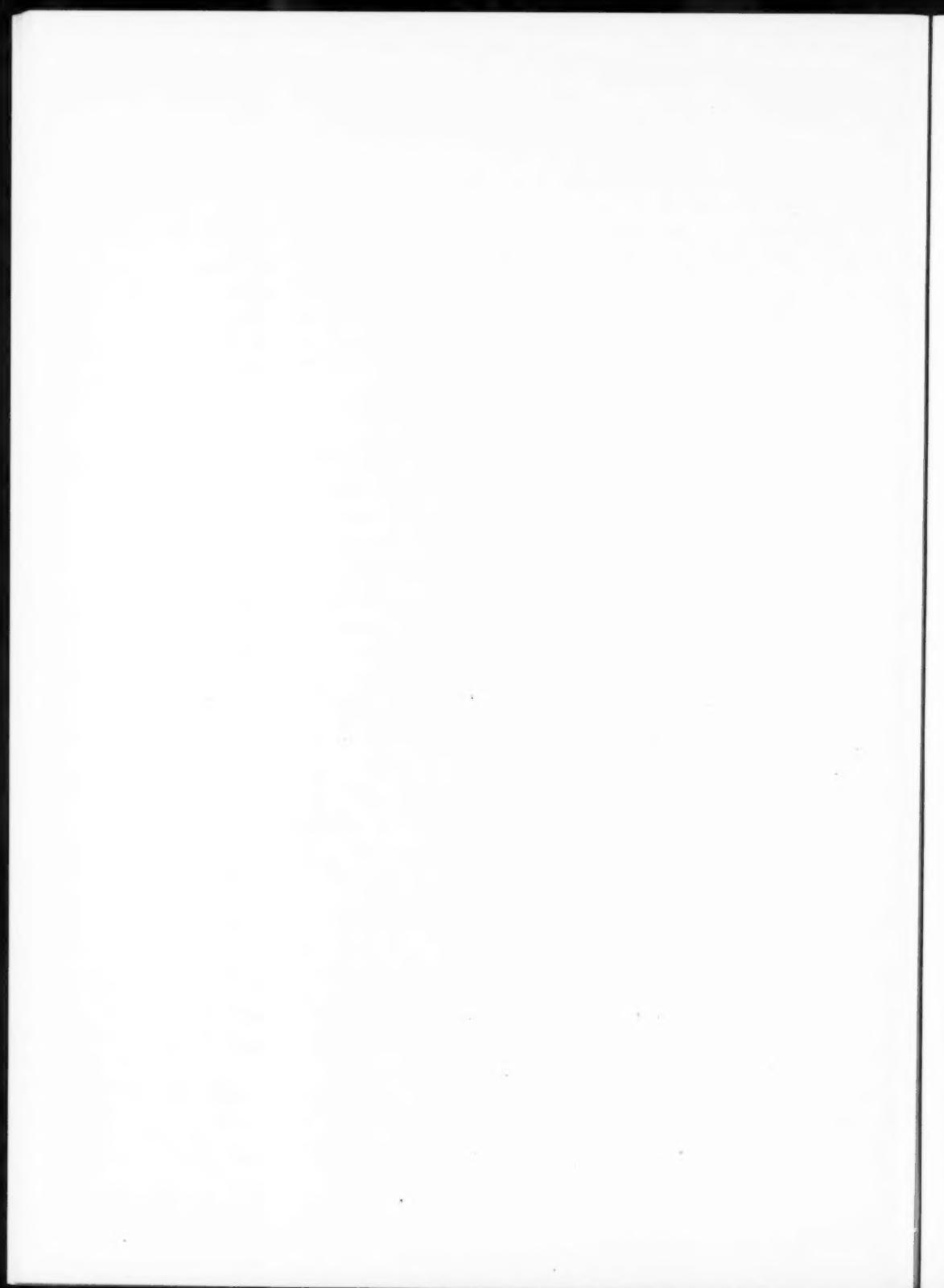
GEO-ELECTRIC INVESTIGATIONS OF NON-CONDUCTORS
—FOUR NEW EXAMPLES[1]

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ABSTRACT

This article is a theoretical and practical explanation of the application of geo-electric methods in oil fields. If favorable subsurface conditions exist, valuable results can be obtained by using several methods in combination. Close coöperation with the geologist is of utmost importance. Four examples of practical, successful work in oil fields of Germany, Poland, and Roumania are given.

This method, as well as every other geophysical method, has caused many debates, and should be used only with the aid of a geologist.

Although the underlying principles of geo-electric investigation can not be considered in this paper, three different methods are mentioned: (1) the integral method, using different frequencies with direct wire connections to the ground, which takes the integral of all current lines, circulating below the receiving set; (2) the potential-difference method, which determines, by means of the quotients of the intensity, the resistance of the different succeeding formations of the subsurface; and (3) the induction method, which determines only good conductors, like salt water, by means of a secondary electromagnetic field.

These three methods can be used as follows: (1) the integral method is used as a reconnaissance measure to discover whether disturbances exist in the magnetic field of force; (2) if such disturbances exist, the potential difference method is used; (3) if necessary, the induction method can be applied to determine the good conductors.

The integral and the potential methods have the advantage in that they are also well qualified to locate deep deposits, as calculations by such geophysicists as J. Königsberger[3] and J. N. Hummel[4] have recently

proved. An experiment in a deep shaft in the Harz Mountains in Germany showed that the intensity at a depth of 3,000 feet was approximately $\frac{1}{4}$ of the intensity measured at the surface. This proves that with normal, natural humidity conditions $\frac{1}{4}$ of the surface current is in circulation at that depth and that it creates strong deformations of the electric-current field, the effect being shown on the picture of the integral current.

The deciding factor is not the proportion of the conductivity, but is the proportion of the differences to the total of the two conductivities. Although the magnitude depending on the conductivities is not definitely or theoretically important, it may have a maximum value if the conductivity of the deposit is either very large or very small in comparison with the semi-sphere of the surroundings. These constants also are obtainable, although the conductivity of the deposit may be ten times smaller or larger than the conductivity of the semi-sphere.

In order to obtain satisfactory results by the electric methods on non-conductors, certain conditions are required. The horizontal extension of the non-conducting matter perpendicular to the current lines must be not less than approximately $\frac{1}{2}$ of the depth; with more favorable conditions, the maximum extension must be not less than $\frac{1}{3}$ of the depth. The decrease of the conductivity of the deposit must be $\frac{1}{5}$-$\frac{1}{10}$ of the normal surrounding mass, according to the theoretical articles by Königsberger and Hummel. The depth of the deposit can be determined from the changes of the curvature of deformed current lines, and by a special grouping of the sending and receiving stations, namely, the placing of the electrodes at variable distances, from the deformation zone, obtained by reconnaissance investigation.

The maximum influence of deformations can be obtained best in the outer space of the electrodes, on the extension of the connecting line of two point-electrodes, which is called the dipole axis. The distance from the nearest electrode must be at least equal to the depth of the center of the deposit, but it is not necessary that deposits be close to the surface, as some geophysicists assert.

It is always advisable to take the readings outside of the densest concentration of the current lines, preferably near the adjoining area of the outer extension of the dipole axis. The skin effect in this outer space has no noticeable influence, because the current lines can not be attracted by the connecting wire. Field experiments and calculations have shown that the skin effect is very small, when frequencies below

500 Hertz (cycles) are used. Greater depth effects can be obtained with lower frequencies.

Inasmuch as it is difficult to determine the nature of the deviations obtained by the integral method, such determinations have to be made with other geo-electric methods, namely, the so-called quotient method, and the intensity and induction methods. The geological conditions and the problem to be solved determine which one should be used.

In locating non-conductors at great depth, another factor must be considered, which was recently investigated, both theoretically and practically, by another physical method. The electrical properties of the oil deposits extend farther than the deposit can be profitably worked. Laboratory tests showed that a sand originally saturated with oil, then charged with salt water, retains oil by capillary attraction, and is, therefore, a poorer conductor than normally wet sand not impregnated by oil. Gas, mostly methane, slowly, but continuously, emanates from the deposits, especially deposits of light oil. This gas diffuses and travels very slowly upward, extending either in a large diffusion cone or along faults or other structures. Gas pushes the water out of the pores and fissures of the rocks and formations, and makes them non-conducting. For example, coal containing carbonic acid is a perfect insulator. However, if coal is of natural humidity and does not contain carbonic acid, it conducts like the surrounding rocks. In some places this gas diffusion has caused deformations, distinct but limited in area.

To prove that accurate results are obtained by geo-electric methods, four examples are cited, which show the great advantage these instruments offer geologists and oil companies.

The first example is the investigation made in Germany on the flanks of the Ilsede and Nienhagen salt domes. Old formations, which have been pushed up, surround these salt domes in some places, like saddles. At the edges of these saddles, oil deposits are known to exist in the Jurassic, Cretaceous, and, in some places, Tertiary formations.

In Oberg, on the flank of the Ilsede salt dome, the Jurassic anticline is 750 feet below the surface (Fig. 1). The apex and the strike of the anticline are geologically known. The anticline dips southeast. Considerable oil has been produced from several wells on the apex of the anticline, at depths as great as 1,600 feet. Geologists surmised that the productive oil zone extended around the anticline, the boundary of which was not known. It was supposed that adjacent to the petroliferous area there is a syncline with salt-water horizons. The area (approximately

GEOLOGICAL and SCHEMATIC SECTIONS of the SALTDOME
and
JURASSIC - SADDLE
of
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LEGEND:

b	Tertiary	Cr	lower Cretaceous	M	Triassic
S₃ S₂ S₅ } Senon		Z	Zechstein	RS	Red Sandstone
		Cw	Wealden		
		Jw, Jᴮ, Jₗ Jurassic		
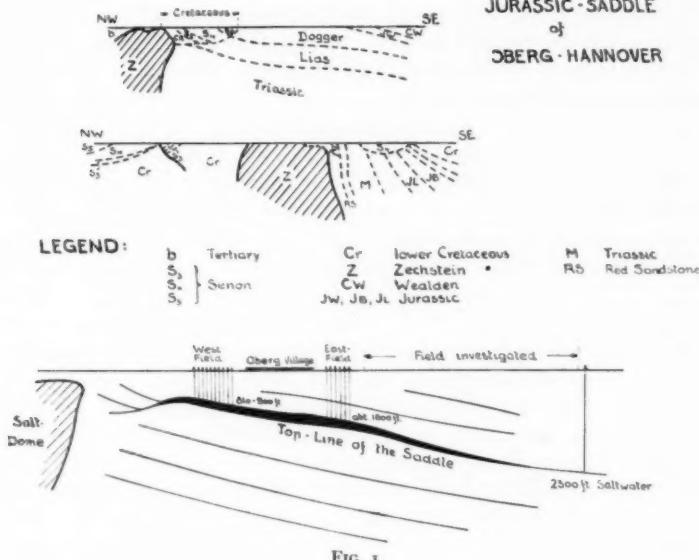
FIG. 1.

1 square mile) investigated by all methods was adjacent to the known productive zone and included also the area in which geologists expected to find a salt-water horizon (Fig. 2). The interpretation of all the measurements by the integral method indicated three different zones: at the north, a very poor conducting zone, adjoining a strip of changing conductivity, and in the south a decidedly good conducting zone. The quotients obtained with the potential-difference method indicated that the poor conducting zone was entirely non-conducting, with a slope of approximately 15° SE. The induction measurements confirmed the good conductor at the south, showing that salt water must be present at a depth of approximately 2,400 feet. The boundary shown in Figure 2 is partly determined by well 61, well Egon, and well 66, drilled or finished after the survey. Salt water was encountered at 2,400 feet in well Robert in the southern part of the field, but there was no showing of oil. Because of the dip of the anticline, the oil is displaced gradually by the salt-water horizon. This displacement explains the previously mentioned doubtful zone.

SKETCH OF THE RESULTS of the combined
geoelectric   Investigations near
OBERG · HANNOVER

Elbofmethod – Potentialdifferencemethod
– Inductionmethod

LEGEND:
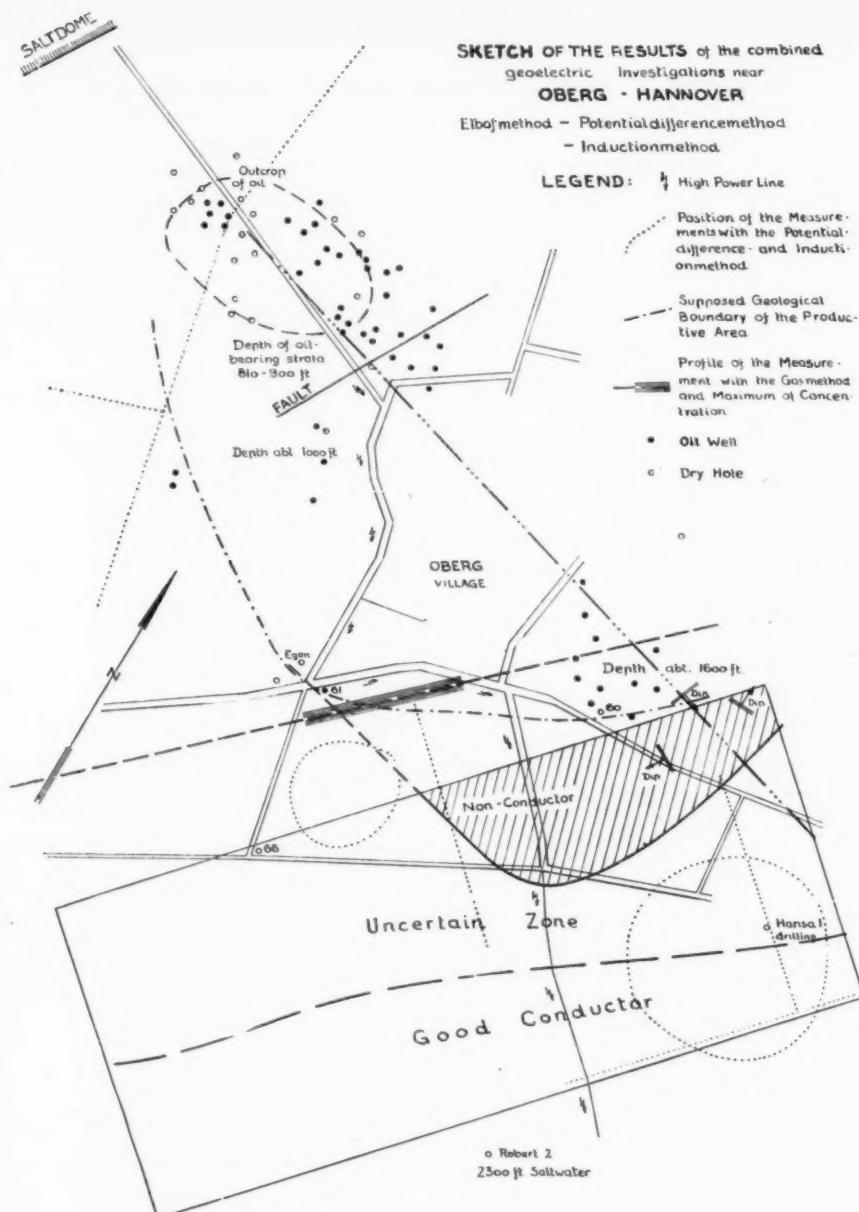
FIG. 2.

The second example is an investigation on the boundary of the Jurassic anticline near the Nienhagen salt dome (Fig. 3). A strip of good oil-producing zone in the Jurassic and the Cretaceous formations is proved by many wells. Oil is produced from these formations on the anticline and the flank of the salt dome. The geologists and the oil companies supposed that this strip of the producing zone also followed the turning of the salt dome at its northern end. Drilling was done at the assumed northern edge of the Jurassic saddle, but no oil horizons were found there.

A simple electric survey in 1925 indicated a non-conducting zone northwest of the already known productive zone, in a direction not
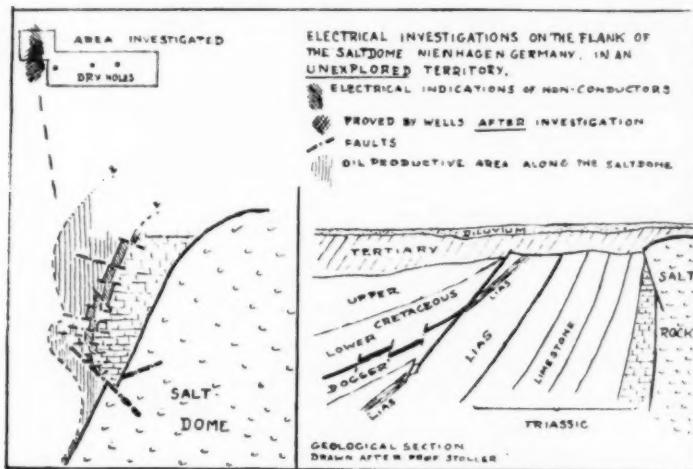
FIG. 3.

expected by the geologists. The electric indications were not believed at that time, but a check survey, made 1 year later, which indicated again the strip of the non-conducting zone in the same northwestern direction, vindicated the electric method. A new drilling company, 2 years later, made the first test in the southern extension of the previously mentioned strip, and encountered oil at 2,400 feet, in commercial quantities. There are now approximately twelve wells in this new field. Exact boundaries of the non-conducting area were, of course, not determined by this simple investigation, which used only the integral methods of the early days. But the important fact is that electric methods were the first to define the non-conductor in this wholly unexplored territory.

A third example shows the application of electric investigations in a folded territory in Poland, between the well known anticlines of Boryslaw and Schodnica. Cretaceous formations have been folded and uplifted many times. Oil horizons occur on the tops of these anticlines (Fig. 4) and salt water is encountered in the synclines between the anticlines.
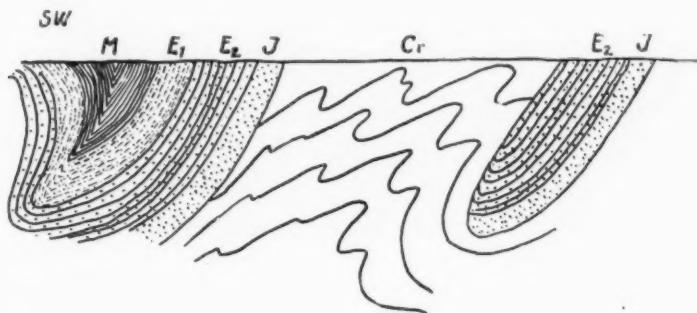
M = MENILITESLATES, LOWER OLIGOCENE   J = JAMNA SANDSTONE
E₁ = UPPER EOCENE   Cr = CRETACEOUS
E₂ = LOWER EOCENE

FIG. 4.—Diagrammatic section of anticlines of Schodnica and Wapaniarka, Poland.

The task was to explore the structure in an area of approximately 3 square miles, and to outline on which one of the geologically assumed anticlines non-conductors exist. The results are shown in Figure 5. A very distinct anticline in the western part is rather wide and plainly indicated by the electrical data. This main anticline becomes smaller toward the southeast and disappears below the Eocene sandstone at the south. A distinct zone of non-conductors, measured also by the intensity method, was indicated on the top of the anticline; good conductors, such as salt water, were distinctly shown on both sides. This anticline has a small fracture (dislocation) which was distinctly indicated by the electric survey. In the center of the investigated field, a broken zone with mostly good conductors was indicated, and in the eastern part two anticlinal ridges, seemingly almost parallel, did not show any poor conductors. An approximate depth of 900 feet was determined in the western part, and 1,200 feet in the eastern part, where the anticline disappears.

RESULTS OF THE GEOELECTRIC INVESTIGATIONS near SCHODNICA - POLAND
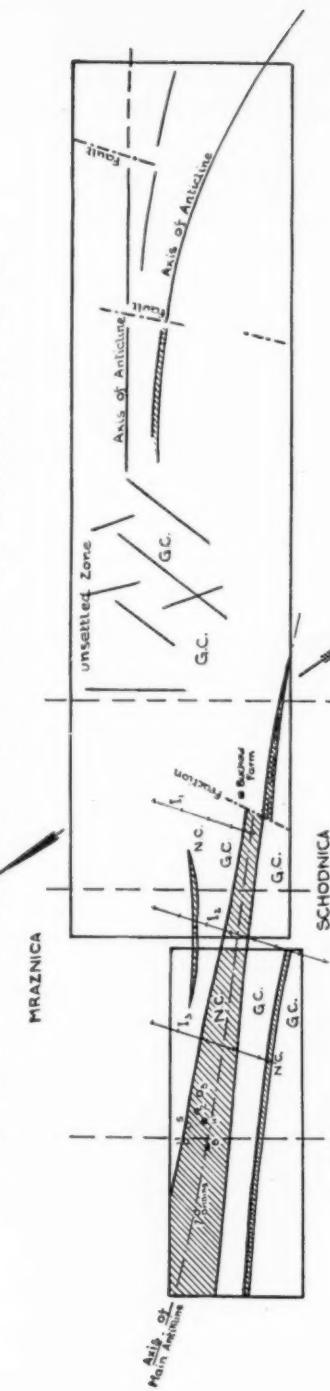
SCHEMATIC SECTIONS OF THE MAIN ANTICLINE

Sw.   Saltwater
I₁,₂,₃ Profiles with Intensity Method
G.C.   Good Conductor
N.C.   Non-Conductor

FIG. 5.

Several wells were already drilled before the investigations were made. Some of them had encountered salt water, and some were producing oil at a depth of approximately 1,200 feet. These wells, however, were not located exactly on top of the anticline. After the investigations, wells 5 and 6 were drilled exactly on the indicated apex, and both produced oil in larger quantities than the wells already drilled. The company geologist, in close coöperation with the party making the interpretation, confirmed the electric results in all points. The electric data obtained outlined the structure and the presence of non-conductors exactly and in detail.

The fourth example is the result of the investigation near the Moreni salt dome in Roumania.[1] Tertiary formations raised on the flanks of the dome (Fig. 6) contain extraordinarily productive oil horizons. The productive zone of Moreni was known to extend almost around the salt dome, except on the southeastern flank. Therefore, the extension of the oil horizons toward the south had to be determined. It was thought that a large syncline, containing salt water, adjoined the oil horizons, and it was important to know how far drilling could be extended without encountering salt water. The undrilled area of approximately 1 square mile south of the wells already drilled was investigated (Fig. 7). The investigation located a very good conducting zone south and east of the territory, whereas non-conducting zones prevailed in the northern part. A definite boundary could not be found because of the dissemination caused by the overlying formations, but a strip indicating the changing conductivity was outlined. North of this strip lies the non-conductor; south and east a good conductor exists. Within the stated boundary of the poor conductor, two wells were drilled, one in the western part, and the other in the northeastern part. Both wells produced from the same horizons, at approximately 3,000 feet. This indicates that the course of the boundary of the poor conductor actually turns toward the northeast, because, if it went in a different direction, the oil-bearing formations in the eastern well would be at a shallower depth.

Other examples of the successful application of the different electric methods can not be given in this paper. However, some of the possibilities of these methods used on non-conductors in American oil fields are cited. Practical experience during several years has shown that these methods are especially suitable where distinct structural conditions

[1]Toma P. Ghitulescu, "Sur l'application des méthodes géophysiques à la prospection du sous-sol en Roumanie." Extrait de la revue les *Annales des Mines de Roumanie*, Anée 13, No. 1 (1930). Bucharest, Roumania.

GENERAL VIEW OF THE MORENI SALTDOME
and its PRODUCTIVE OIL ZONE

CIUJU ANTICLINE

BANA ANTICLINE

MORENI SALTDOME

N.C. GC.

LEGEND:

Salt dome (Diapir fault) with tilted over parts

Known productive zone of oil

Unknown zone

Indicated boundary-line between good and non-conductors

Contour lines of depths of oil strata

Well drilled after the investigation got the oil at 3,000 feet

N.C. Non-conductor

G.C. Good conductor

GEOLOGIC CROSS SECTION

S

Field investigated

Levantine

Dacic

Pontic

Moreni

Bana

SALT DOME

Ciuju

Levantine

Dacic

Pontic

Maeotic

N

Fig. 6.

MORENI - ROUMANIA
TERR.2 ELECTR.17
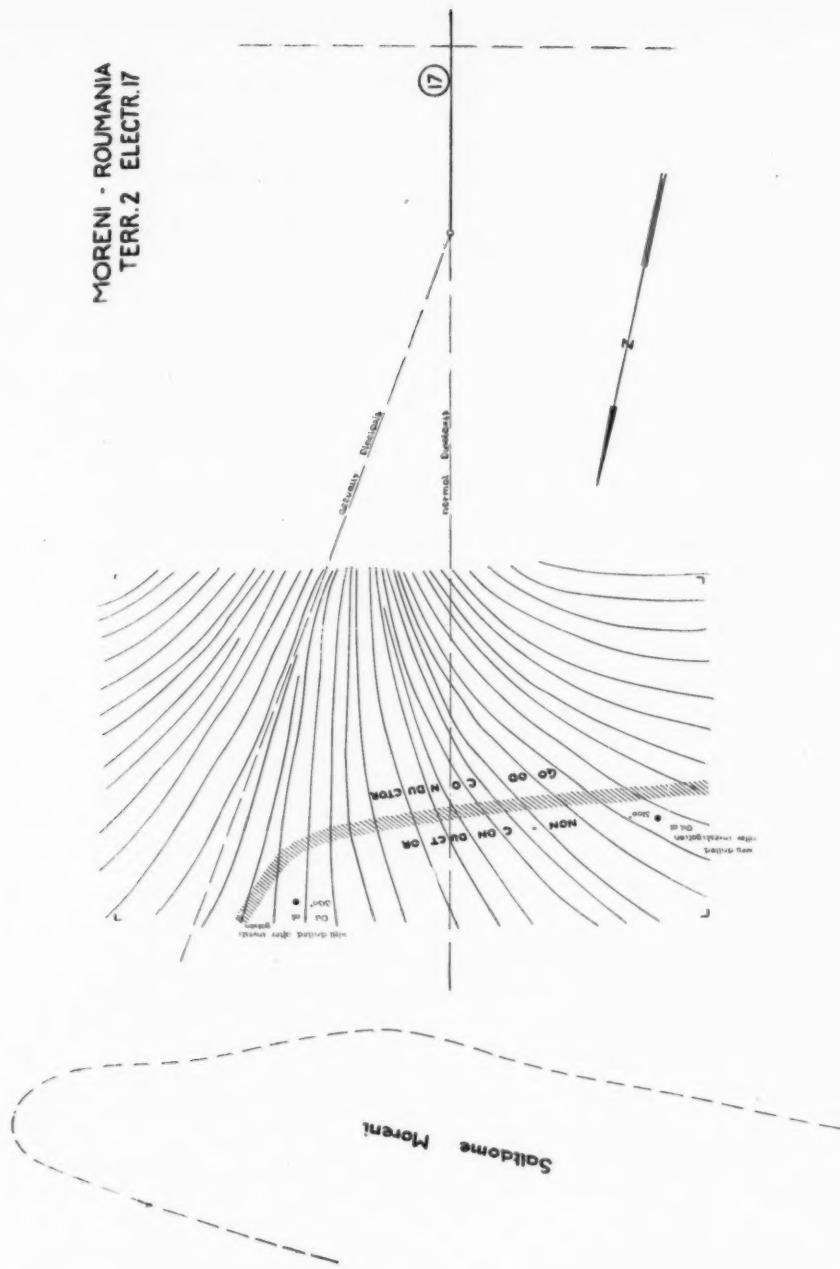
Fig. 7.

prevail, and where the horizontal extension of the oil deposits is in the required ratio to the depth of the horizons expected to be productive. Sand lenses, as they occur in some West Texas territories at shallow depths, can also be determined by these methods. The boundaries of the productive areas can, of course, also be determined. The dip of conducting or non-conducting formations, as in the pools in northwest Texas, can be indicated by these methods, although the slope may be only a few degrees.

It may at first thought seem surprising that electric investigations include a smaller area per month than the torsion-balance or seismic methods. The reason for this is that electric investigations represent work of a more detailed nature because actual field work is itself detailed. The fact must also be taken into consideration that geo-electric methods are quite different from the methods of field surveys. It is difficult to state the time required for an electric survey, because this depends on the conditions of the particular territory and special problems involved. Generally, a survey of approximately 2 square miles necessitates 1 month of work. After deformation zones have been defined, more detailed work is required. The advice of the local geologist also must be secured.

The writer hopes that in the near future more use will be made of electric methods in American oil fields, to the end that they may prove in this country, also, their effectiveness under favorable conditions. The fact is again emphasized that coöperation with geologists is positively necessary where geo-electrical or any other geophysical methods are used. The application of other geophysical methods is also advisable in order to check results secured by geo-electrical methods.

ELECTRICAL SURVEY OF STRUCTURAL CONDITIONS IN SALT FLAT FIELD, CALDWELL COUNTY, TEXAS[1]

HELMER HEDSTROM[2]

Houston, Texas

ABSTRACT

The writer points out the difficulties in mapping the oil structure of the Balcones fault zone in Texas in the usual way, by a study of surface geology. Core drilling has been used in many places, but has not proved very successful on account of the uncertainty involved in identifying the beds and in correlating them between holes.

He discusses the application, in this area, of the Sundberg electromagnetic method of mapping structure, describing the basic principles and showing it to be much superior to core drilling in speed and efficiency.

The survey made by the Sundberg method in the Salt Flat, or Bruner, oil field was begun in October, 1928, when only the discovery well was productive, and before the trend of the producing fault structure was known. The fault was mapped electrically by one surveying crew in about a month, and the later development of the field has proved the results correct, as shown by the map. A comparison of these electrical results with the data obtained from later drilling gave excellent agreement, as shown by five different profiles across the field.

GENERAL

The Salt Flat, or Bruner, oil field is situated on the northeast side and in the immediate vicinity of the town of Luling, Caldwell County, Texas, in a flat or gently rolling country. The surface beds belong to the Wilcox formation, of Eocene age, composed of sands and clays, weathering to yellow or reddish brown clayey sand. The beds have a southeast dip of 4-5 per cent and are nearly parallel with the underlying Cretaceous beds, the top of which occurs at a depth of about 1,000 feet.

The field is one of the many related to the well known Balcones fault zone, which extends at least 350 miles approximately southwest and northeast through the eastern part of Texas. It was developed in the latter part of 1928 and was the second oil field of the Balcones fault zone to be productive from the Edwards limestone (Lower Cretaceous), which is here found at a depth of 2,700 feet. Some oil is also produced from the Austin chalk of the Upper Cretaceous, at a depth of 2,300 feet.

[1] Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, March 6, 1930.

[2] Field manager, Swedish American Prospecting Corporation. Introduced by D. C. Barton.

STRUCTURAL GEOLOGY

The oil pools of this region are located along the traces of faults, which occur *en échelon* in a zone approximately parallel with the Balcones zone, but 20-35 miles on the east, or gulfward side, of this great displacement. The main Balcones fault system is characterized by a large downthrow on the east side, but the "secondary" zone of faults, which has caused the structure favorable for oil accumulation, has the downthrow on the west side, that is, on the side up the dip of the sedimentary beds. Where a fault in this zone is of such size that it can be traced along the strike of the beds for miles, and especially where it curves in such a way that both ends trend down the dip of the beds, closures are formed which have been found favorable for oil accumulation.

CONDITIONS AFFECTING GEOLOGIC MAPPING OF STRUCTURES

The main problem in the search for new oil fields in this area is to find the fault structures and to map their trend. This can be done by a study of the surface geology, because there is no disconformity of importance between the producing horizons and the surface beds.

In this surface work one must consider, however, that the surface reflection of the faulting in the competent Cretaceous beds may be very weak, because of lessening of the displacement in passage through the soft and yielding Tertiary beds. The fault plane, also, may change from the steep west dip that is characteristic in the Cretaceous beds, to a very gentle, or almost horizontal, dip at the surface, as a result of absorption of the vertical displacement along the bedding planes of the unconsolidated clays, shales, and sandstones. In some places it has not been possible to find at the surface any trace of pronounced faults found by drilling in the Cretaceous beds, the faulting evidently being of pre-Tertiary age. Further, there is the possibility that minor faults may be present in the surface beds, which disappear within relatively shallow depths and which are not directly connected with any faulting in the deep-seated competent Cretaceous beds.

As most of the known producing faults can be traced, however, on the surface, a study of the surface geology is most important in the search for new oil fields in the Balcones fault zone. Unfortunately, this surface work is very difficult and unsatisfactory because most of the surface is soil or recent alluvium and because the definite beds that do crop out ordinarily lack fossils and differentiating lithologic features. Core drilling has been used in many places, but correlation of the Wilcox sand and clay

beds between different drill holes has proved somewhat doubtful because of the lens-like character of the beds, and other irregularities. In order to obtain reliable results from core drilling for the study of surface geology in this area, the drill holes must be spaced comparatively close, which, of course, makes the method slow and expensive.

SUNDBERG ELECTROMAGNETIC METHOD FOR STRUCTURE STUDIES

A geophysical method for the study of structure at moderate depths, which has been successfully used in the Balcones fault zone during the last 3 years, is the electromagnetic method of Sundberg, which is more fully described in another paper.[1] This method is based on the fact that there exist in the sedimentary column certain beds, or a system of beds, which on account of their electrical conductivity cause a pronounced shielding effect on electromagnetic fields penetrating into the subsurface. This reaction of such subsurface beds can be measured on the surface of the ground, and from the data thus obtained it is possible to compute the depth to the corresponding bed and also its electrical characteristics, the so-called induction factor, which depends on its thickness and its electrical conductivity.

The electrical conductivity of sedimentary beds is due to the water held in their pores, and to the salt content of that water, saline water being a good conductor of electricity. As the salinity of the water held in the pores, as well as the water content, varies considerably between successive members of the sedimentary column, there are everywhere certain beds or a system of beds with a considerably higher induction factor than adjacent beds, which are therefore suitable as key beds for structure mapping by the electromagnetic method. Figure 1 shows that each of the different formations represented in the surface beds along the Balcones fault zone has its characterizing average electrical conductivity. The data given in this figure were compiled from many resistivity determinations of the surface beds in different localities, using the Gish-Rooney principles. Similar pictures are obtained if each of the formations shown in the figure is divided into its different members. There is an alternation of blocks in the sedimentary column, each with its characterizing conductivity and thickness, and among these are to be found the key beds of the electromagnetic method of Sundberg.

Along the sedimentary beds, however, the combined effect of conductivity and thickness, that is, the induction factor for a certain system

[1] Karl Sundberg, "Electrical Prospecting for Oil Structure," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 9 (September, 1930), pp. 1145-1163.

Generalized Profile Through Outcrops of the Series
Taylor - Cook Mountain.
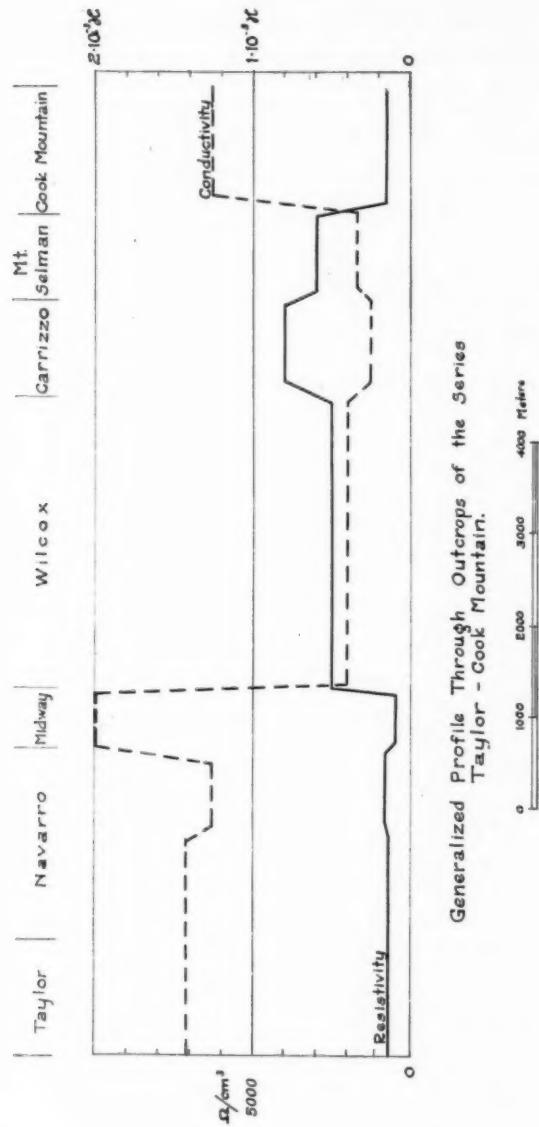
FIG. 1.—Electrical conductivity of surface beds in Balcones fault zone.

of beds, changes only very gradually, if it changes at all. This makes it possible to identify and follow through a considerable area the same electrical key bed, the configuration of which, of course, corresponds with the geologic structure.

It can be shown theoretically that most of the electrical key beds, determined by the electromagnetic method, must correspond with a series of strata at least 200 feet thick. Such a key bed therefore includes, for example, many of the sandy clay and clayey sand members of the Wilcox formation in Texas, and a pinching-out of a few of these members consequently does not affect the individual characteristics of the electrical key bed nearly as much as it affects the correlation between core-drill holes. It is further known that nearly all of the horizons of saline water, which are the ultimate cause of the conductivity of the key beds, parallel the geologic structure, and that they keep their characteristic salinity very persistently, though the sedimentary beds they follow may be subject to abrupt thinning or thickening.

It seems reasonable to suppose, therefore, that the trouble, resulting from pinching or gradual change of the sedimentary beds, encountered by an electromagnetic survey of electrical key horizons, will be less than the trouble encountered in a structure study based on correlation between core-drill logs.

The Sundberg method is much more rapid than core drilling, one electrical surveying crew completing 250-300 points of observation a month, compared with the 15-20 drill holes of 500-600 feet depth that the more expensive core drilling can average per month. It is therefore economical to put the observation points of the electromagnetic method comparatively close together, which also makes it possible to follow the electrical key horizon continuously throughout long distances, without the danger of losing the key bed between observation points, as happens in core drilling, because of pinching.

Everything considered, it seems, therefore, that the Sundberg method of structure mapping, compared with core drilling, is much more efficient and better adapted to the local conditions in the Balcones fault zone.

APPLICATION OF SUNDBERG METHOD IN SALT FLAT FIELD

In the Salt Flat field the Sundberg method was used in October, 1928, almost at the same time that the first Edwards limestone well was completed, commencing the drilling campaign in the field. Until that time only a small amount of oil had been produced from a few wells
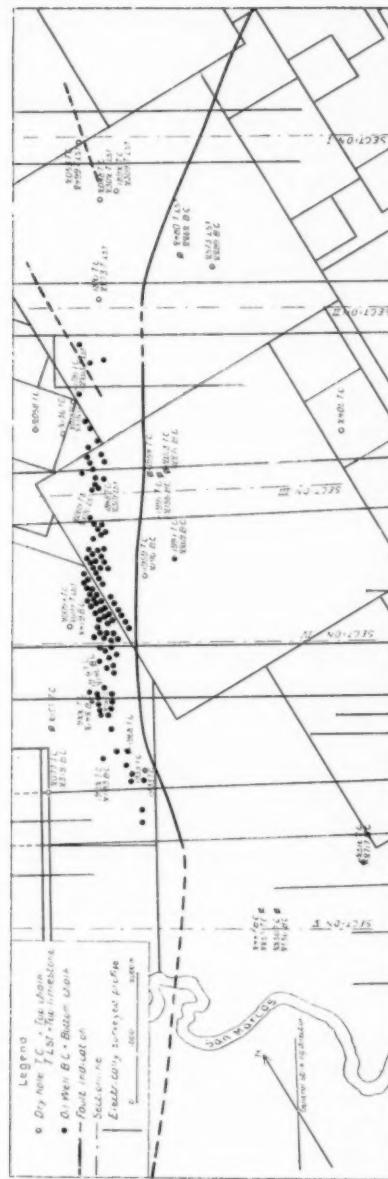
Fig. 2.—Electrical map of Salt Flat (Bruner) fault.

completed in the Austin chalk. The scant geologic information obtained from these wells had indicated the probability of an important oil pool at greater depth, in the Edwards limestone, and, although the trend of the producing fault structure was not known, a large tract of land had already been leased when the discovery Edwards limestone well was completed.

The electrical survey was made along profiles staked on the ground, approximately at right angles to the anticipated trend of the fault structure, and spaced ½-1 mile apart, as shown in Figure 2. Along each of these profiles was laid out a thin insulated copper cable, several miles in length. Through the cable was sent an alternating electric current, supplied by a generator outfit, carried on a small truck. The electromagnetic field thus set up around the electric current in the wire was measured, in regard to direction, strength, and phase, at different distances from the cable, along short transverse lines staked at right angles to the long profiles. The measuring apparatus, consisting of a search coil, compensator arrangement, and amplifier, was carried by two men assisting the observer. The cross lines, each representing one station of depth determination to electrical key beds, were spaced 600 feet apart along the profiles. On an average, eleven such stations were surveyed per day and per surveying crew, making a total length of profile surveyed of about 1½ miles per day, including all computing and office work.

The electrical key bed followed by this survey occurred at depths ranging from 400 to 700 feet. As shown in the five sections of Figure 3, which are parallel with the surveyed profiles, the variation of the depth determined to the key bed indicates, in the course of several miles, a slight dip toward the southeast. In places this gradual increase of depth eastward is suddenly interrupted, and the key bed appears a few hundred yards farther southeast on a considerably higher plane. The points on the different surveyed profiles where these displacements occur, as shown in Figure 2, are in one continuous line, which represents the trend of a fault in the Wilcox beds.

The long "electrical fault," shown in Figure 2, was mapped by the Sundberg method in approximately 1 month. Throughout a large part of its length the fault indicated a closure, and, as shown by the figure, that part of the electrical indication is parallel with the producing area developed by later drilling.

In order to compare the fault structure found electrically in the Wilcox beds with the structure of the deep-seated Cretaceous beds as revealed by later drilling, five sections across the Salt Flat oil field have

SECTIONS ACROSS BRUNER FAULT, TEXAS
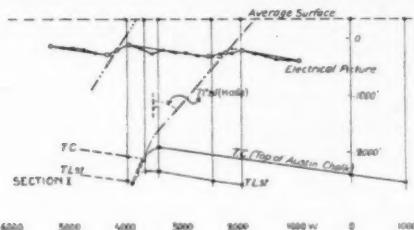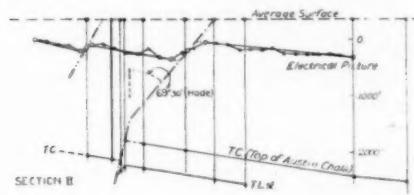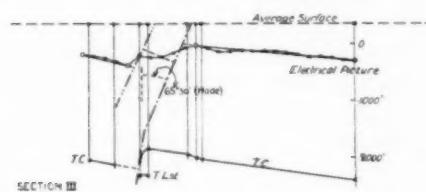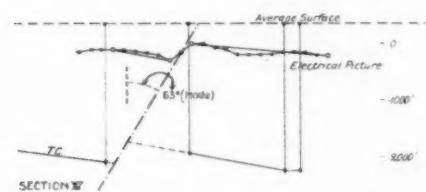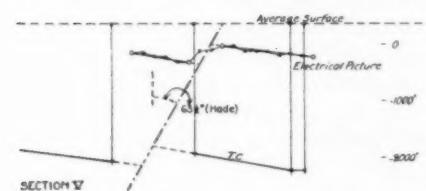
Fig. 3.—Comparison between electrical results and geologic structure in Salt Flat (Bruner) field. Horizontal scale in meters; vertical, in feet. The angle of hade shown in each section is correct although the drawing does not show the graphic or true size of the angle because horizontal and vertical scales are not the same.

been constructed, along the lines shown in Figure 2. On these sections adjacent drill holes have been projected, with the data that have been published regarding the depths found to the geological key horizons of the Cretaceous.

The result of the comparison is given in Figure 3, where the five sections are plotted. This figure shows that, with an assumed average dip of the fault plane varying from 20° in the northern part of the field to 27° in the southern part, the electrical fault indications are in excellent agreement with the displacements found by drilling in the Austin chalk and deeper strata.
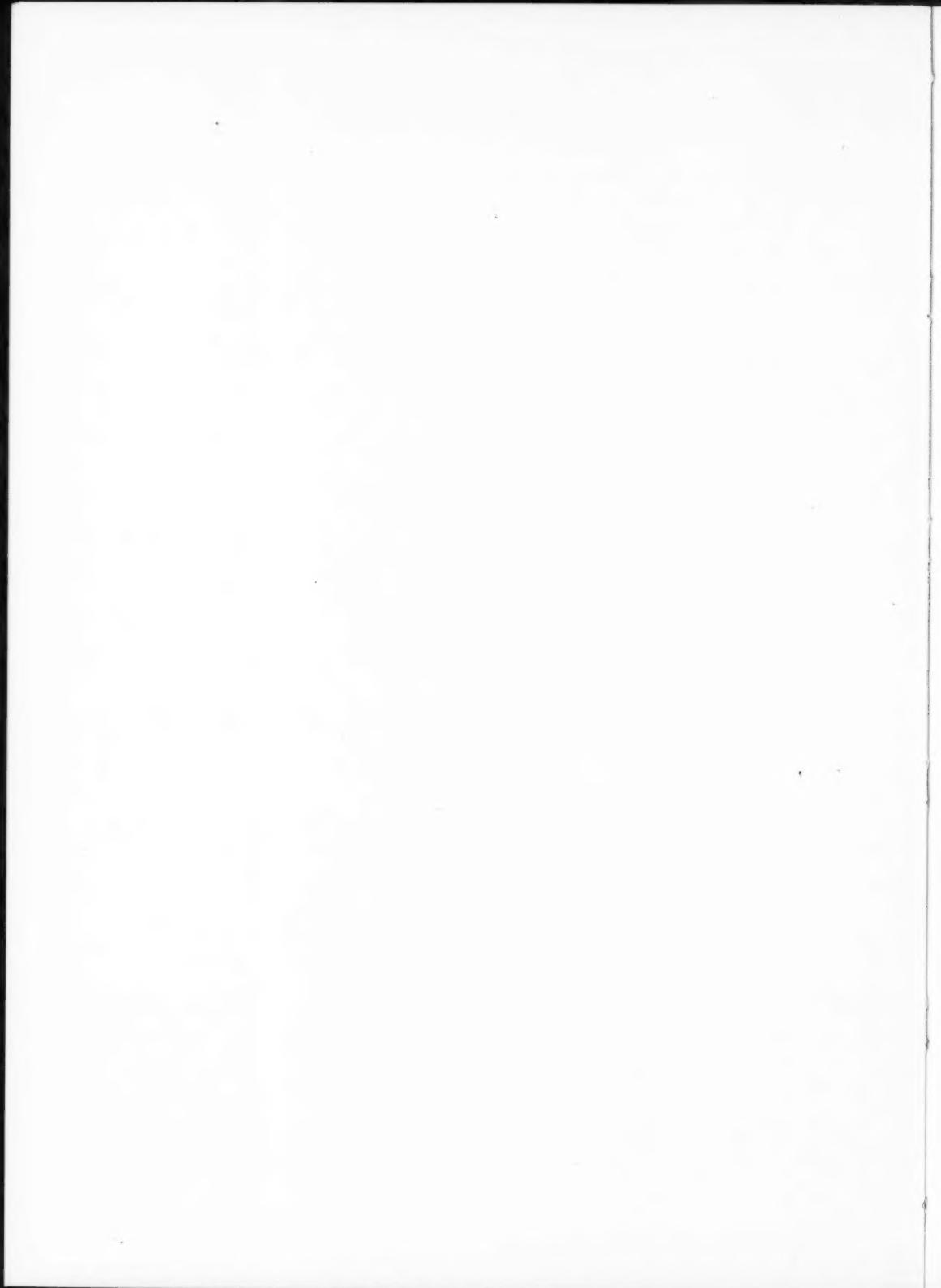
MAGNETIC SUSCEPTIBILITY AND MAGNETITE CONTENT OF SANDS AND SHALES[1]

D. M. COLLINGWOOD[2]
Dallas, Texas

ABSTRACT

During a study of the relation between small magnetic anomalies of a local survey and the magnetic susceptibility of the rocks, chiefly sands and shales, comprising the surface outcrop and shallow section, several susceptibility determinations of core samples were made. These were made in a field laboratory by means of an apparatus consisting of a laboratory magnetometer and energized solenoids in which the core specimens were placed. The core samples were classified according to lithology, and the percentage of magnetic minerals (chiefly magnetite) in them was determined. The susceptibility determinations were made in a field of approximately 18 gauss. For this and other possible reasons, they are not considered true in an absolute sense for rocks in place in the earth's field. However, the results, which are true in a relative sense, show a definite increase of susceptibility with increase of magnetic mineral content, and indicate that the susceptibility increases from shales through sandy shales and shaly sands to sands.

While making a systematic geological study of an area in La Salle and McMullen counties, Texas, which included a study of the Fayette and Yegua formations at the surface, the writer had an opportunity to check geophysical surveys with a detailed structural survey by core drill.

In connection with the magnetometer survey of the area, magnetic susceptibility determinations of many core samples were made as they were taken from the drill. A mineralogical analysis of these core samples was made, and the percentage of magnetic minerals approximately determined. Correlations were made between the magnetic susceptibilities of the rock samples and their content of magnetic grains, also between the average susceptibilities of the beds and formations in the shallow section and the relative magnetic intensities at the surface observed during the survey of the outcrops of the section studied.

The susceptibility determinations were made in an apparatus consisting of solenoids and a laboratory magnetometer. The effect on the magnetometer needle of magnetic induction in the core sample, when

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[1] Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, May 20, 1930. Published by permission of the Sun Oil Company, Dallas, Texas.

[2] Geologist, Sun Oil Company.

placed inside energized solenoids, was measured by a comparison solenoid
in which the current was regulated to give the same deflection of the mag-
netometer.   This delicate apparatus, having several other features in
order to obtain accurate results, was constructed, at the suggestion of the
writer, by John A. Goff, a physicist then in the employ of the Sun Oil
Company.   The apparatus was installed in a tent on a vibration-proof
table with concrete supports, and, under adverse field conditions, was
successfully operated by Goff.

The susceptibilities thus measured were determined in a field of
approximately 18 gauss, or approximately 40 times the vertical com-
ponent of the earth's field for that locality.   For this and other possible
reasons the results probably do not represent absolute values of the sus-
ceptibility of the rocks as they exist in place in the earth's crust.   How-
ever, the values were accurately checked and are true in a relative sense.

In determining the content of magnetic minerals, 19 typical samples
of the cores used for the susceptibility measurements were weighed,
washed until they disintegrated, and the soluble, colloidal, and suspended
matter decanted.   After the total residue had been weighed, the mag-
netic grains were removed with a magnet and weighed.   The results,
indicating a direct relation between magnetic susceptibility and content
of magnetic minerals (chiefly magnetite), are shown in Table I and
Figure 1.
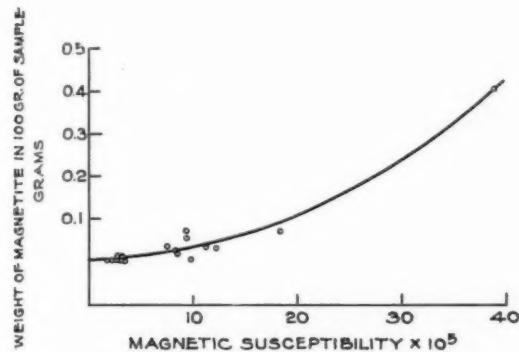
Fig. 1.—Curve showing relation between magnetic mineral content and mag-
netic susceptibility.

TABLE I

Speci-men	Weight of Sample Before Washing (Grams)	Weight of Sample After Washing (Grams)	Weight of Magnetic Minerals (Grams)	Magnetic Susceptibility ×10³
D50-282	100	0.9	......	2.31
D42-119	100	14.2	......	2.77
D9A-325	100	24.1	......	3.01
D19-100	100	37.2	......	3.05
D13-386	100	36.0	......	3.17
D23- 50	100	39.2	0.0019	3.18
D49-100	100	1.7	......	3.19.
D25-104	100	1.0	......	3.31
D13-383	100	31.7	0.0011	3.42
D33- 97	100	38.0	0.0369	7.66
D16-193	100	46.5	0.0273	8.15
D35-218	100	37.7	0.0156	8.60
D19- 41	100	59.3	0.0678	9.30
D28-225	70	23.1	0.0362	9.30
D43-401	83	24.0	0.0066	9.84
D19- 53	100	60.3	0.0338	11.20
D 1-444	100	33.3	0.0301	12.20
D28- 82	100	29.2	0.0732	18.40
D16-107	100	41.0	0.4060	38.70

The core samples used for susceptibility tests were also classified according to their lithologic properties. Thus, most of the samples were grouped as follows: shales, sandy shales, shaly sands, and sands. Table II shows the results of averaging the values of susceptibility of the samples in each group.

TABLE II

Group	Susceptibility	
	Number of Samples	Average Susceptibility ×10⁵
Shales	55	4.44
Sandy shales	201	4.75
Shaly sands	20	5.38
Sands	17	9.08
Total	293	4.98
Grand total of all specimens tested	376	4.96

The results shown in Table II indicate that the magnetic susceptibility is somewhat higher for the sands than for the shales, and that it

increases from the shales through sandy shales and shaly sands to the sands.

In some places a correlation was also possible between slight local anomalies of the magnetic areal survey and the outcrops of the beds of which samples showed high susceptibility. Inasmuch as such a correlation was not uniformly evident, these data are not considered sufficiently conclusive for presentation in this paper. The writer suggests that this was due in part to using an insufficient number of representative samples of a sandy bed or a lateral zone to obtain its true average susceptibility, and in part to the masking effect of a regional influence on the magnetic intensity as registered by the magnetometer. However, the relationship indicated was sufficient to demonstrate that outcropping beds of higher average susceptibility than that of adjacent beds or zones have a local influence on the magnetic intensity of the earth's field which can be detected by a careful and detailed survey with the type of magnetometer in general use by oil companies.

MAGNETICS AND GEOLOGY OF YOAST FIELD, BASTROP COUNTY, TEXAS[1]

D. M. COLLINGWOOD[2]
Dallas, Texas

ABSTRACT

The relation between the geology of the productive "serpentine" mass and the results of a magnetic vertical intensity survey is illustrated by maps, charts, cross section, and profile.

The writer concludes that the high magnetic anomaly is due to an igneous neck in a major fault plane, up which the igneous rock came as a volcanic submarine extrusion at the close of Austin chalk deposition of the Upper Cretaceous. Other geologic evidence indicates that the faulting which occurred during the succeeding Taylor or Navarro deposition was later increased by post-Wilcox (Eocene) faulting, and he suggests that this earlier faulting occurred mostly in association with the igneous activity.

The writer suggests that the search for such serpentine masses in this region constitutes a special field for magnetics with certain limitations. Inasmuch as plugs or vent fillings generally cause the anomaly, lateral bodies with no vent filling remaining in the channels up which the flow came are probably not indicated. However, where a plug effect is indicated by magnetic anomaly, a productive lateral or domal body of serpentine is found in many places.

Early in 1927, the Johnson Brothers' Trigg No. 1, in the south part of the area shown in Figure 1, was drilled to the Edwards limestone. Although this test failed to make a commercial producer, it had a considerable showing of oil at the top of a mass of altered igneous rock generally known as serpentine. Approximately 80 feet of this rock was found overlying the Austin chalk formation of the Upper Cretaceous. Interbedded serpentine and chalk were also logged in the upper part of the Austin, and serpentine was found in a core taken in the Edwards limestone (Lower Cretaceous). After this discovery, a magnetic survey of the adjacent territory, including the area now occupied by the Yoast oil field, was made by the Sun Oil Company under the direction of the writer.

A local high anomaly in vertical intensity found on the Yoast tract was interpreted as being caused by a small plug of serpentine or group of vent fillings. The discovery of the Yoast field, late in 1928, and the data

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[1] Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received by the editor, May 20, 1930. Published by permission of the Sun Oil Company, Dallas, Texas.

[2] Geologist, Sun Oil Company.

supplied by drilling a productive domal mass of serpentine situated on a major fault have corroborated this interpretation.[1]

The magnetic chart is shown in Figure 1. Figure 2, an enlargement of the producing area, shows the inner magnetic closures and the sub-surface contours on the top of the serpentine mass. Figure 3 shows a geologic cross section and magnetic profile across the area along line *XY* (Fig. 1).

GEOLOGIC SUMMARY

· *Surface.*—The Wilcox and Midway formations of the Eocene occur at the surface. Outcrops are adequate for a fairly accurate mapping of the surface trace of two parallel faults with a strike approximately N. 45° E. and a downthrow toward the northwest. These faults are part of a major belt of faulting associated with the Balcones fault zone.

Subsurface.—Wildcat drilling has supplied control in mapping the subsurface position of the faults and the general stratigraphy. At the east, or upthrown side of the fault at the west edge of the Yoast field, the depth to the horizon of the top of the Austin chalk is estimated to be approximately 1,500 feet, although here, as in the Lytton Springs serpentine field, it is probable that some of the upper part of the chalk has been displaced by serpentine.

Data from the following wells, designated by serial letter on the maps and profile, were used in drawing the cross section *XY* (Fig. 3).

(*A*) R. D. Pyle's Storey No. 1
(*B*) Cranfill and Reynolds' Yoast No. 6
(*C*) Cranfill and Reynolds' Yoast No. 3
(*D*) Cranfill and Reynolds' Yoast No. 5
(*E*) The Texas Company's Yoast No. 2
(*F*) The Texas Company's Yoast No. 3
(*G*) The Texas Company's Yoast No. 4
(*H*) The Texas Company's Yoast No. 5
(*I*) The Texas Company's Yoast No. 6
(*J*) J. Jarmon's C. J. Barnett No. 1
(*K*) J. Storey's Pearson No. 1

[1]For discussions of similar occurrences see the following.
H. P. Bybee and R. T. Short, "The Lytton Springs Oil Field," *Univ. Texas Bull.* 2539 (October 15, 1925).
D. M. Collingwood and R. E. Rettger, "The Lytton Springs Oil Field, Caldwell County, Texas, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 10 (October, 1926), pp. 953-75.
J. T. Lonsdale, "Igneous Rocks of the Balcones Fault Region of Texas," *Univ. Texas Bull.* 2744 (November 22, 1927), pp. 110-52.
J. A. Udden and H. P. Bybee, "The Thrall Oil Field," *Univ. Texas Bull.* 66 (1916).
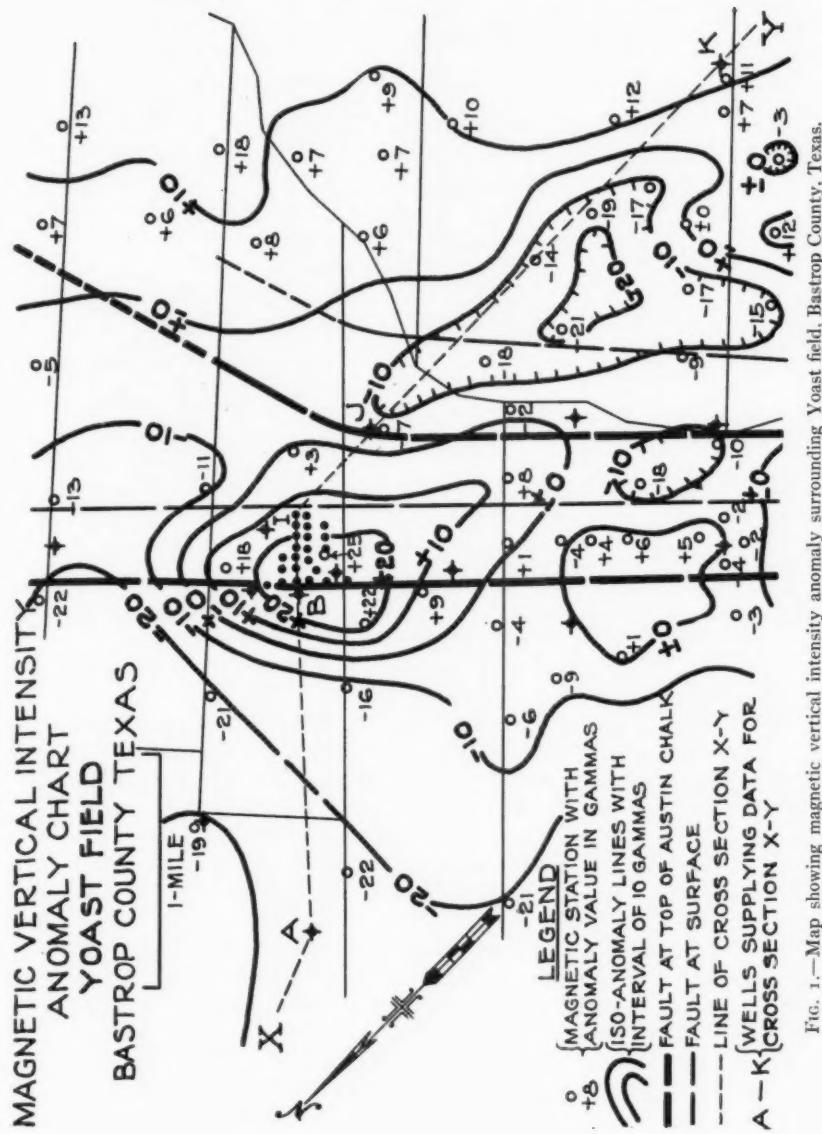
FIG. 1.—Map showing magnetic vertical intensity anomaly surrounding Yoast field, Bastrop County, Texas.
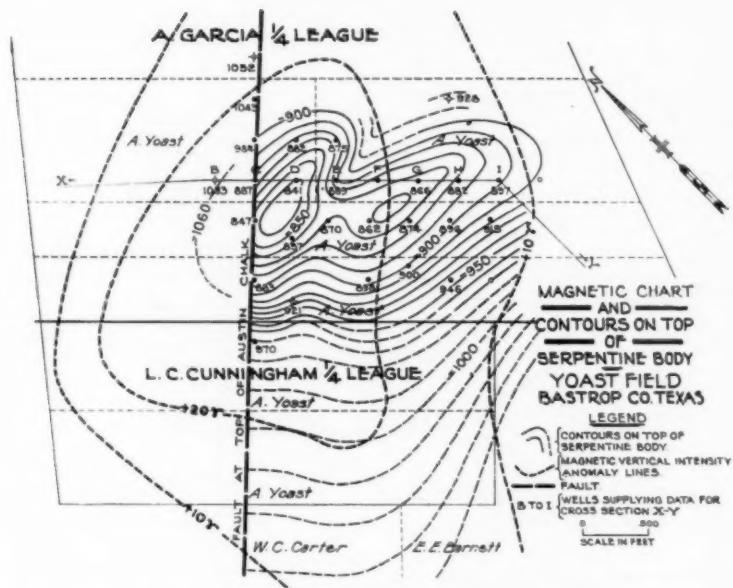
FIG. 2.—Map showing magnetic vertical intensity anomaly and contours on top of serpentine mass, Yoast field, Bastrop County, Texas.

MAGNETICS

Method of survey.—A more or less detailed survey was made. Traverse readings of vertical intensity were taken at stations ranging from $3/10$ to $1/2$ mile apart, the location depending on accessibility from base stations. Corrections were made for diurnal variation and for the average gradient due to magnetic latitude and longitude position. The maximum checking error was approximately 10 gammas, the average being approximately 5 gammas. Iso-anomaly lines are drawn with an interval of 10 gammas.

In accordance with improved technique and standards, this survey would now be considered too incomplete and stations would be more closely and regularly spaced, with checking errors reduced and closure errors better distributed.

Local anomaly.—A pronounced magnetic high anomaly with more than 25 gammas closure was found surrounding the area in the Yoast tract where production from serpentine has subsequently been found.
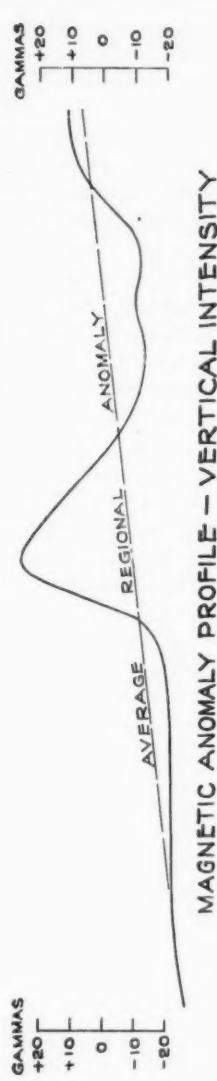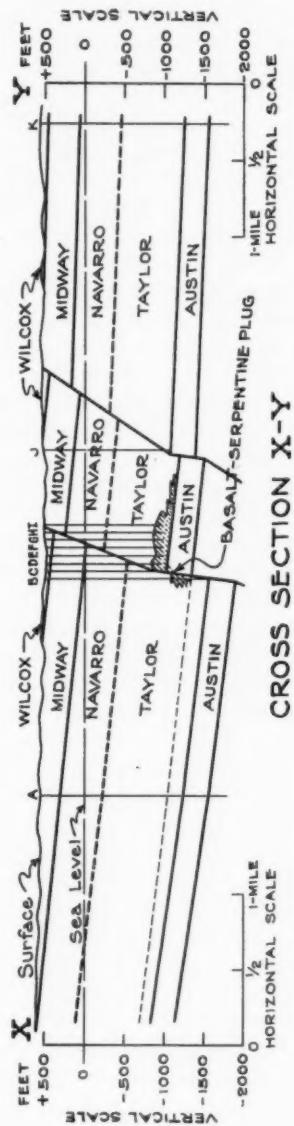
FIG. 3.—Cross section along line *X-Y* (Fig. 1), and profile of magnetic vertical intensity anomaly.

Furthermore, the center of the inner closure coincides with the center of the west line of producing wells, which have been drilled along the fault in the serpentine horizon.

CONCLUSIONS

Magnetic.—Inasmuch as the center of the vertical intensity high anomaly occurs over the fault near the highest part of the mushroom top of the serpentine mass, the writer infers that the high anomaly is due to a small neck or vent fillings of igneous rock in the fault plane below the top of the Austin chalk.

As is to be expected, the high anomaly does not conform exactly with the extent or thickness of the lateral mass of serpentine. Because of the inclination of the earth's field and the downward continuity of any plug or neck, the distortion in vertical intensity caused by such necks is of a much higher order than the distortion in vertical intensity caused by lateral bodies at the same depth, although the latter may be several hundred feet thick.

Geologic.—The stratigraphic relationship of the serpentine mass indicates that the igneous extrusion (probably submarine) occurred at the end of Austin time. Inasmuch as the magnetic results indicate igneous vent fillings in the fault plane, the writer infers that the serpentine mass is related to an igneous flow associated with faulting which was previous to, or contemporaneous with, the flow at the end of Austin time.

The extra thickness of the Taylor-Navarro section of approximately 200 feet on the downthrown side of the fault indicates the amount of fault displacement occurring between the end of Austin and the end of Navarro time. Most of this displacement probably occurred at the time of the igneous activity at the end of Austin deposition, although some intermittent faulting may have continued during Taylor-Navarro time.

Subsequent faulting in post-Wilcox time, which extended the fault plane to the surface, resulted in a displacement of approximately 300 feet in the surface formations, and increased the displacement in the Austin from 200 to 500 feet. Conditions similar, except that the earlier faulting occurred in mid-Austin time, are indicated in the Lytton Springs serpentine field.[1]

Special field for magnetometer, with limitations.—In many places in this general fault-zone area, surface structural evidence of a buried domal mass of serpentine can not be easily discovered. Outcrops are in many places too scarce or of a nature not suitable for detail work. Little struc-

[1]D. M. Collingwood and R. E. Rettger, *op. cit.*, pp. 958-61.

tural expression may be present in some surface beds. There is, therefore, a special need for magnetics in such areas, in addition to the need for checking areas where surface geology suggests the presence of a serpentine mass. The magnetometer will locate a neck or vent filling of igneous rock where the top of the neck lies as deep as, or deeper than, 2,250 feet, although the upper part may be altered to serpentine. The size of the vertical intensity anomaly varies directly as a function of the susceptibility and the cross-sectional area of the igneous neck, and inversely as a function of the depth to its top.

Lateral masses of porous serpentine, whether entirely extrusive or partly sedimentary, will probably yield oil and are generally found in association with plugs and vent fillings. The lateral bodies themselves, however, rarely cause sufficient anomaly to be recognized by magnetometer surveys.

Although the available field evidence is somewhat limited, there seem to be places where no plug effects have been found in connection with a productive lateral mass of serpentine that can not be classified as entirely sedimentary. The writer believes, as Lonsdale[1] suggested, that although a large igneous flow may have occurred in these areas, the vent filling remaining is of very small cross-sectional area or thickness. Such small vent fillings may cause no appreciable distortion of the vertical intensity at the surface.

In searching for new serpentine fields in this region, it is to be expected that some will be overlooked for the foregoing reason. However, in many places where a plug effect is found in territory otherwise geologically favorable for oil accumulation, a productive serpentine mass associated with the plug will be found.

[1]*Op. cit.*
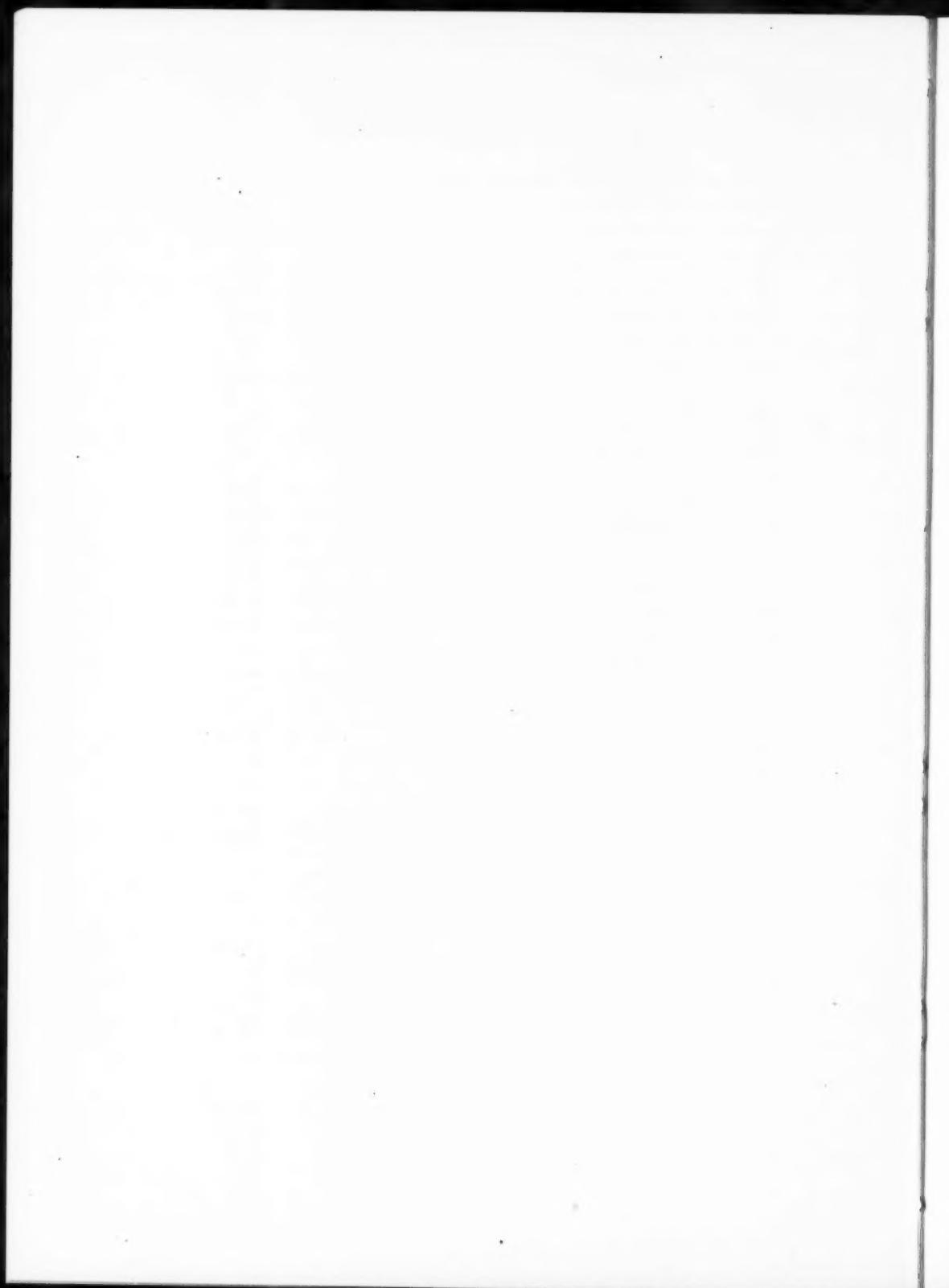
ELECTRIC AND ELECTROMAGNETIC PROSPECTING
FOR OIL[1]

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ABSTRACT

General geologic problems of electric oil prospecting are discussed and the main theories for electric and electromagnetic oil prospecting developed. According to practical experience, the average depth reached by electric surveys is less than 600 feet. Interpretations based on simple assumptions ordinarily approach the actual geologic conditions more closely than interpretations based on complicated theories.

Extended electric and electromagnetic surveys for oil have been made in the United States, in Roumania, Poland, Austria, Germany, and France, to determine structure or to locate oil directly as a non-conductor.

The few results published have proved to the most skeptical geologist or geophysicist that under some conditions electric methods have been successful, though the general attitude of the oil companies shows that the commercial value of electric prospecting is still disputed.

The chief difficulty with electric oil prospecting and the cause of the little success heretofore is the same as with other geophysical methods in former years, or possibly now: too much mathematics and physics and too little geology.

This circumstance is especially bad in electric prospecting because no other geophysical method is so dependent on surface geologic information as are the electric methods.

The practical results of both electric and electromagnetic surveys have shown that the changes in the electric or electromagnetic field which are still perceptible at the surface, occur normally at depths not more than 600 feet below the surface.

It must be borne in mind that the percentile distribution of the electric and electromagnetic field in the subsurface is the same for any primary current strength, so that it is useless to try to penetrate deeper by stronger primary currents, if through the increase in the primary

[1] Manuscript received by the editor, April 10, 1930.

[2] Magnolia Petroleum Company.

current strength a decrease of the sensitiveness of the recording appara-
tus is necessitated, or if the shallow layers contribute an excessive per-
centage to the total field.

Inasmuch as the electric investigation is limited to the first few hun-
dred feet below the surface, any change in the geologic conditions of the
shallow subsurface and especially of the surface, intensively influences
the electric or electromagnetic field.

The same is partly true, also, of the other methods. The difference,
however, is that the main influence in gravimetric, seismic, and magnetic
measurements is as a rule deeper-seated and the first few hundred feet of
subsurface represents only a part, though in places a large part, of the
total influence.

A close examination of the surface and shallow subsurface geology
may therefore increase the accuracy of the gravimetric, seismic, or mag-
netic measurements and permit a better interpretation of the deeper
main influences.

A close examination of the surface and shallow subsurface geology
may, however, explain the total electric or electromagnetic result. An
"anticline," found electromagnetically, for example, may be only a
thickening of a surface clay bed; and measurements interpreted as a
fault may be the result of a contact between sand and clay beds.

Elaborate theories for the electric and electromagnetic field above
one, two, three, and more layers of different resistivities have been es-
tablished. Practical experience, however, has shown that interpretations
based upon simple assumptions generally approach the actual geologic
conditions more closely than interpretations based upon complicated
theories.

GEOLOGICAL PROBLEMS[1]

Inasmuch as oil occurs, practically without exception, in the sedi-
ments, the fundamental problem in electric prospecting for oil is the
electric conductivity of the sedimentary rocks.

This problem is closely connected with the problem of oil accumula-
tion itself and is related to the percentile pore volume and the size of the
individual pores of the sedimentary rocks.

The theoretical maximum for the pore volume in any rock, provided
that all individual particles touch one another, is 47.6 per cent. This
maximum is reached if the individual particles are of spherical shape and

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[1] E. Blumer, *Geologie der Oellagerstätten* (Leipzig, 1922).

of equal diameter. The pore volume is independent of the actual size of the grains.

The permeability of a rock, however, is largely dependent on the size of the individual particles.

The pore volume of volcanic rocks ranges from 0.1 to 2 per cent. The average pore volume of limestone is 10 per cent, of sandstone 10-30 per cent, of clays, shales, and marls 20-40 per cent.

The individual particles, therefore the interstices, are smallest in clay, shale, and marl, and largest in sand and sandstone.

These characteristics of the sedimentary rocks are important in regard to their electric conductivity, as the conductivity is directly proportional to the water volume in the rocks and to the grade of mineralization of this water. The water volume is approximately the same as the pore volume, and the grade of mineralization is very dependent on the permeability of the rocks, that is, the size of the individual pores. Shallow sands and sand beds, because of their large pores, are ordinarily much more washed out and their water less mineralized than the water in the clay beds. The water in clay beds may even be of primary salinity, because of the small pores and strong adhesion, which retained fossil water through ages.

Most of the clays, therefore, are good electric conductors, with a resistivity as low as 400 ohms per cubic centimeter, whereas the sands are poor conductors with a resistivity ranging from 2,000 to 20,000 ohms per cubic centimeter, though the water volume in both materials may be approximately the same.

As oil generally occurs at depths greater than those reached by electric surveys, the mapping of structure by a close examination of certain conducting beds at depths ranging from 100 to 600 feet is the general method of electric or electromagnetic prospecting for oil.

In the exceptional conditions of shallow-oil occurrences it might be possible to detect oil directly as a non-conductor.

Of much more importance for electric prospecting, however, is the good conducting property of the salt waters commonly related to oil deposits. These salt waters are much more widespread along the oil-bearing structures and may occur at shallow depths.

The strong salt-water solutions in the vicinity of salt domes, the salt waters in northwest Texas and Roumania, represent ideal conductors for electric subsurface investigation.

ELECTRIC PROSPECTING FOR OIL[1]

Shallow structures may be determined electrically either by tracing equipotential lines or by measuring the resistivity of the ground along the surface or in drill holes.

In homogeneous ground the equipotential surfaces with reference to two point electrodes are given by the equation:

$$P = \frac{E}{2}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) = C$$

where r_1 ar.d r_2 are the distances of the equipotential surface P from the two point electrodes, and E is the potential between the electrodes.

The result is that the equipotential surface, which passes through the middle point between the two electrodes, is a vertical plane perpendicular to the connecting line of the electrodes. On both sides of the middle point, the equipotential surfaces are more and more bent until near the electrodes they are practically half spheres with the electrodes as center.

To trace the equipotential lines a simple arrangement is used. Two electrodes are placed at a distance of about 1 mile and connected with a direct current or an alternating current generator of 1-2 kilowatts. Two search electrodes, non-polarizable if direct current is used, are then placed at a distance of 50 yards in such a way that one search electrode is stable and the other is movable until the galvanometer, if direct current is used, or the phone connected with a compensator, if alternating current is used, indicates no current flowing between the two search electrodes, which means that they are on an equipotential line.

Any change of conductivity in the surface or shallow subsurface between the two current electrodes of course greatly influences the current path, and consequently the equipotential lines.

It is easy to see that on account of the strong salt waters near and above the salt domes, the top of a shallow salt dome would be practically on equal potential at any place and that the equipotential lines near the salt dome would circle around the dome.

If folds are measured, the distance between equipotential lines, corresponding with equal voltage drop, is larger or smaller above an anticlinal structure, if the conductivity of the material of the structure is more or less than the conductivity of the material of the overlying beds.

[1]*Geophysical Prospecting, 1929*, Amer. Inst. Min. Met. Eng., pp. 51-237.

If faults are measured, the equipotential lines, corresponding with equal voltage drop, are spaced differently on both sides of the fault, if, through the fault, a change in the conductivity of the shallow subsurface has been effected.

Similar distortions are also obtained, however, by surface contacts between good and poor conducting materials, for example, between clays and sands.

Approximately, the percentage of the current distributions in a series of layers is inversely proportional to the resistivity of these layers.

If the layers have a small dip and the surface layer has a much larger conductivity than the shallow subsurface layer, practically the whole current passes through the surface layer and the only practical use of electric prospecting in such areas is the determination of the thickness of the surface layer.

This can be done by tracing the equipotential lines as already described, or by simple resistivity measurements.

The fundamental formula for resistivity measurements is:

$$R = C \frac{V}{I}$$

where V is the electric potential between two search electrodes, I the current strength, R the resistivity in ohms per cubic centimeter of the ground between the two electrodes, and C a constant that is dependent on the measuring arrangement.

A simple procedure for the resistivity determination is given by the Gish-Rooney method. Four electrodes are placed at equal distance from each other. The outer two are used as current electrodes and the inner two as search electrodes. The relation $\frac{V}{I}$ can be calculated from corresponding measurements; C the constant is in this case $4\pi r$, where r is the distance between electrodes. The earth resistivity therefore is: $R = 4\pi r \frac{V}{I}$ *ohms* per *cm³*

For this method a practical instrument, the "megger," is available. The primary current is furnished by a direct-current hand-driven generator. The ratio $\frac{V}{I}$ can be read directly. With this arrangement a

depth is reached nearly equal to the electrode spacing, so that by varying the spacing between electrodes, the different conductivities of the shallow layers and the thickness of these layers can be determined. Thus, it is possible to follow certain geologic contacts through areas with vegetation or shallow overburden.

ELECTROMAGNETIC PROSPECTING FOR OIL

An insulated cable, 2 or 3 miles in length, is laid out straight and grounded on each end. An alternating current which is sent through this cable creates a primary electromagnetic field, which rotates perpendicularly to the cable. This primary electromagnetic field induces in the ground a secondary electromagnetic field, which normally also rotates perpendicularly to the cable, but in the opposite direction to the primary field. From the measurement of the resulting electromagnetic field at different distances from both sides of, and along, the cable, conclusions can be drawn as to the depths and quality of the conducting layers in the ground.

The primary field can be calculated by the formula shown in Figure 1.

$$H_p = \frac{I}{d}\left(\sin a_1 \pm \sin a_2\right)$$
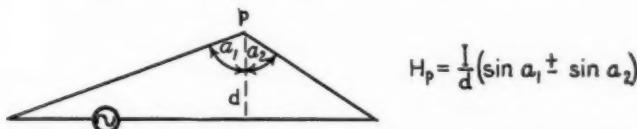
FIG. 1.—I is the current strength in ampere, d the perpendicular distance between a point P and the cable, a_1 and a_2 the angles between the perpendicular d and the connecting lines of the point P with the electrodes.

The secondary field may be calculated as follows. We assume that beneath the cable there is a thin and infinite good conducting layer of infinite horizontal extensions. In this case the secondary electromagnetic field at the surface corresponds with a field created by the same, but reversed, primary current at double the depth of the layer. The resulting total field at various distances from the cable and for different depths of the layer can easily be calculated by the angle relation and the distances from the primary and secondary sources. For the vertical and the horizontal components of the resulting electromagnetic field we obtain the following formulas.
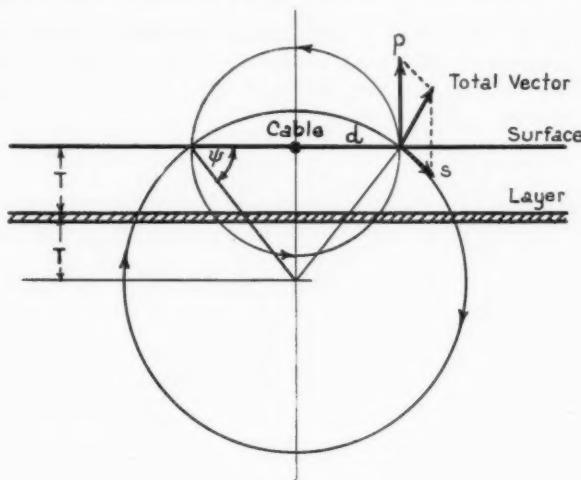
FIG. 2

Vertical component: $VC = \dfrac{2}{d} \sin^2 \psi$ micro gauss/amp.

Horizontal component: $HC = \dfrac{I}{d} \sin 2\,\psi$ micro gauss/amp.

The discussion of these formulas reveals the following general ideas about the electromagnetic field due to an infinite horizontal layer of infinite good conductivity.

ψ	$0°$	$45°$	$90°$
VC	0	$\dfrac{I}{d}$	$\dfrac{2}{d}$
HC	0	$\dfrac{I}{d}$	0

If ψ is $90°$, the layer is very deep and has no influence. Therefore the horizontal component of the total field is zero and the vertical is $\dfrac{2}{d}$, which simply corresponds with the primary field.

If ψ is $45°$, the layer is at a depth equal to half the distance between the observation point and the cable (Fig. 2). Thus, the horizontal and the vertical components are of equal strength, or half the strength of the primary field.

If ψ is $0°$, the layer is at the surface; consequently, it has no horizontal component. The vertical component of the total field is also zero, because the vertical component due to the layer is of equal strength with, but of opposite direction to, the component of the primary field.
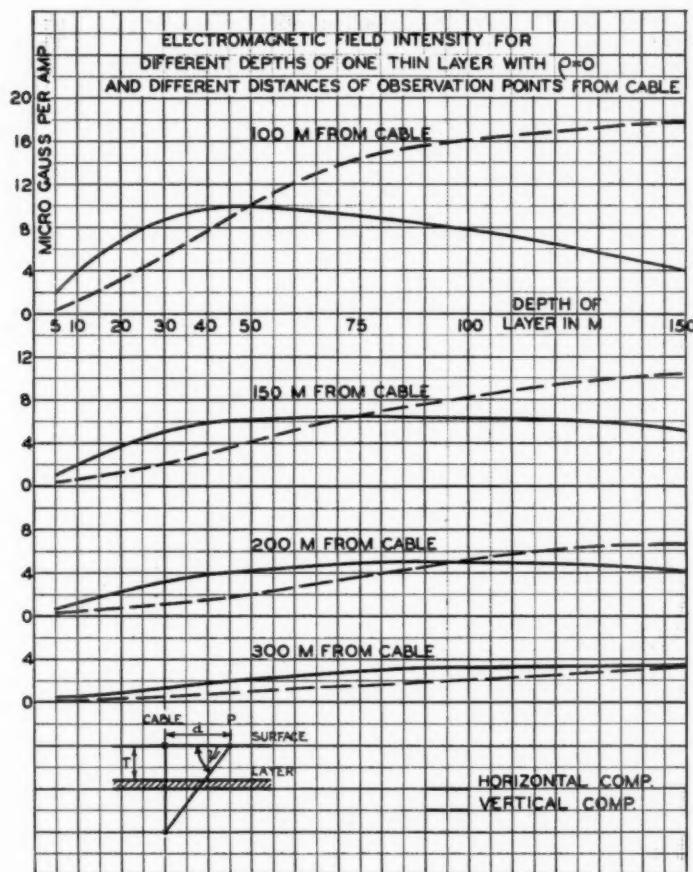
FIG. 3

For depths of the layer ranging from 5 to 150 meters and distances from the cable of 100, 150, 200, and 300 meters, the values for the vertical and horizontal components of the resulting electromagnetic field are shown in Figure 3.

If the layer is of infinite good conductivity, the maximal strengths of the primary and secondary field occur simultaneously. If the layer is, however, not of infinite good conductivity, the maximal strength of the secondary field occurs at a time different from the maximal strength of the primary field. This difference is known as the phase difference and expressed as the phase angle (Fig. 4).
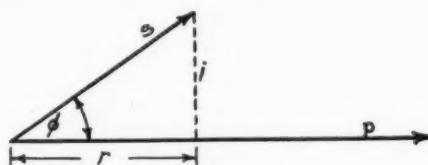
FIG. 4.

ϕ phase angle
p primary vector
s secondary vector
r real component of s
i imaginary component of s

The measuring arrangement must by all means take care of the compensation of the two components of the secondary field, that is, of the real component in phase, or 180° out of phase, with the primary field and the imaginary component plus or minus 90° out of phase with the primary field. This can be done by a compensator combining an ohmic resistance with an inductance or capacitance. The wire resistance serves to compensate the real component, and the inductance or capacitance the imaginary component. The compensating current is taken from the cable.

From general deliberations an approximated diagram (Fig. 5) for the relations between phase and vector may be deduced.

The vertical and horizontal real components of the secondary field are 180° out of phase with the primary field.

The length of the primary vector for a certain distance from the cable determines the shape of the diagram, in such a way that all the imaginary components are considerably smaller than the primary vector, the maximal vertical real component of the same length, and the maximal horizontal real component considerably smaller than the primary vector.
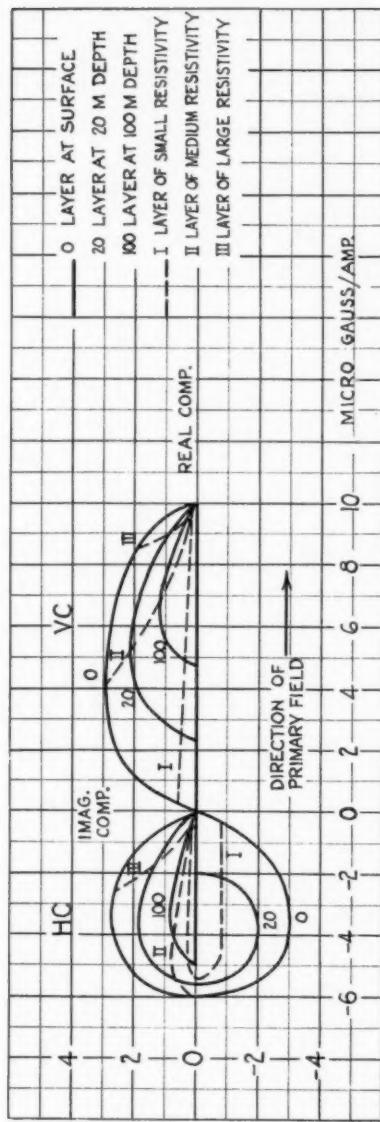
Fig 5

For a surface layer the following characteristics are to be expected with different resistivities of the layer.

For infinite resistivity the vertical component of the total field is simply the primary vector. There is no horizontal component.

For infinite good conductivity, that is, zero-resistivity, the total field is zero.

For intermediate resistivities a phase dispersion takes place. For the horizontal component the total vector due to varying resistivities might be expected to be maximal for medium resistivities and nearly in phase with the primary field, because both extreme values of the resistivity give a zero vector. For the vertical component the extreme values for the resistivity give zero and maximal vectors; therefore, a medium resistivity should yield a medium vector and large phase angle.

Inasmuch as the vector, due to varying resistivities of a layer at a certain depth, may reasonably be assumed to be stronger near the surface than deeper, a schematic diagram (Fig. 5) may be drawn for the horizontal and vertical components of the electromagnetic field 200 meters from the cable.

T. Levi-Civita[1] and F. Pollacek[2] have calculated the potentials of the electromagnetic field for thin and thick conductors of infinite horizontal extensions and various conductivities.

The final expression of Levi-Civita for the potential of the electromagnetic field of a thin conductor is shown in Figure 6, where the sign $l = logarithmus\ naturalis$.

$$U_p = 0.1\ I_o \sin\omega\left\{l\left[y^2+(h+z)^2\right] - l\left[y^2+(h-z)^2\right]\right\} + 0.2\ I_o\ e^{i\left(\omega-\frac{\pi}{2}\right)}\cdot i \int_0^\infty\left[e^{-px}\frac{d}{dz}\left(\frac{l}{\tau}\right)\right]dx$$

I_o = Primary Current in Amps. , $\omega = 2\pi\nu$, ν = frequency

$p = 4\pi^2\frac{\nu\cdot d}{\rho}\cdot 10^{-9}$ (Induction factor)

ρ = resistivity of conductor, $\tau^2 = y^2 + (z+h-x)^2$

d = thickness of conductor, x = an integration const.
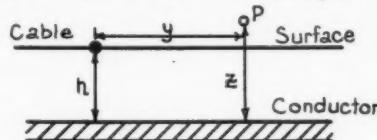
Fig. 6

[1] *Atti della Reale Academia dei Lincei* (Rome, 1902).

[2] *Electrische Nachrichten Technik*, Heft 9 (Berlin, 1926).

Then $H_y = -\dfrac{\delta U}{\delta Z}$ is the horizontal component of the field at point P

and the vertical component is $H_z = \dfrac{\delta U}{\delta Y}$

For the situation where two layers exist, one above the other, Levi-Civita states that the electromagnetic field above the lower layer is the same, whatever the distance between the two layers, provided that the upper layer lies between the lower and the cable.

It seems therefore feasible to calculate the electromagnetic field due to two, three, or more layers by lowering the top layer to the second until the two form practically one layer, then lowering this combination layer to the third, and so on.

However, the question is open whether this can be done, because two layers, as long as they are actually distinct, whatever the distance between them, will create an electromagnetic field distinctly different from the field of one combination layer.

From practical experience the writer came to the conclusion that only under exceptional conditions is a complicated theory for electric or electromagnetic prospecting of value. Though it is necessary that the underlying theories should be studied and understood in all details, yet the interpretation of the readings is best done by simple assumptions, which are logical and agree best with the geologic conditions of the subsurface.

For example, it would be of little use to try to explain the electromagnetic field above an area with outcropping beds, with contacts between good conducting clay beds and non-conducting sands, with faults and other disturbances, by a theory, however complicated it may be, which is based on two, three, or more distinct layers of infinite horizontal extensions.

Practically, we may consider the subsurface as one thick conductor, with varying conductivities of the different strata.

It is generally known that the lower the applied frequency is, the deeper the electromagnetic field penetrates into the ground, or, in other words, the lower the frequency, the larger the contribution to the secondary field from deeper strata.

This results also from the theory of Levi-Civita, which shows that the inductance factor (p) is directly proportional to the frequency; with small inductance, large permeability for low frequency. A layer with 1,000 ohms per cubic centimeter creates the same electromagnetic

field at 300 *cy*, as a layer of the same thickness and 500 ohms per cubic centimeter, at 150 *cy*.

If we had to deal with distinct layers in the subsurface, we could determine the qualities of the layers by applying two frequencies.

Inasmuch, however, as the ground as a whole is conducting, a lowering of the frequency ordinarily means a deeper penetration. The total vector of the lower frequency field should therefore have less phase dispersion than the total vector of the higher frequency.

A study of Figure 3 shows that the ratio between the H and V components for a specified distance from the cable, decreases steadily with increasing depth of the layer.

Depth of layer in meters	25	50	100	150
$\frac{H}{V}$ 100 meters from cable	2	1	0.5	0.33
$\frac{H}{V}$ 150 meters from cable	3	1.5	0.75	0.5
$\frac{H}{V}$ 200 meters from cable	4	2	1	0.67

The result is, that, though the values of the $\frac{H}{V}$ ratio between the different distances from the cable are constant for any depth, the absolute differences of the $\frac{H}{V}$ values decrease considerably with increasing depth of the layer.

This means that with a change in the surface conductivity, there might be expected a considerable difference of the $\frac{H}{V}$ values on both sides of the contact and a material increase in this difference with increasing distance from the cable.

If, however, the change in the electromagnetic field is caused mainly by an uplift of deeper conductors, through faulting or folding, for example, the difference between the $\frac{H}{V}$ values on both sides of the disturbance, though noticeable, will not be large, and the increase of the absolute value of this difference will not be very large with increasing distance from the cable.
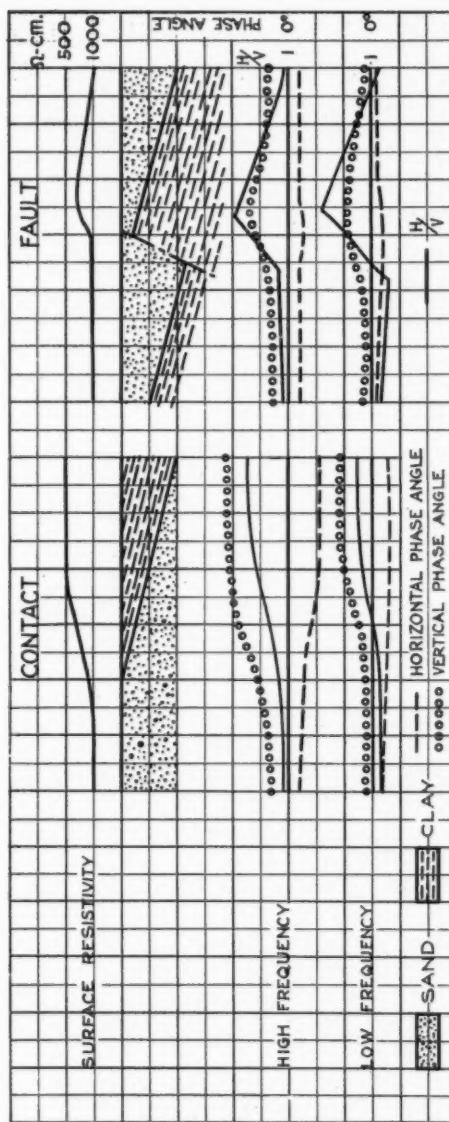
Fig. 7

The phase angles characterize well the conditions on both sides of the indication. With a change in conductivity along the surface, the phase angles may be expected to be considerably different on both sides of the change, but with a tectonic dislocation of a certain deeper conducting layer, the phase angle may be expected to vary only slightly.

If two frequencies are used, the lower frequency would penetrate deeper; that is, compared with the higher frequency, the difference of the

$\dfrac{H}{V}$ values for the lower frequency, on both sides of a surface indication,

should be much smaller and, at a fault, the same or larger.

The phase dispersion of the lower frequency would be smaller than that of the higher frequency under any condition.

The picture of a surface and fault indication by the $\dfrac{H}{V}$ method is shown schematically in Figure 7.

The study of the percentile change of the total vectors along the profiles, or the study of the differences of the readings on both sides of the cable are other simple and effective methods of locating and distinguishing the disturbances of the electromagnetic field.

There may be great doubts about one, two, three, or more conductors in the subsurface with large horizontal extensions. Also, the other assumptions necessary for the application of complicated theories may not only be without geological meaning, but may even prove disastrous for a geological interpretation.

There is, however, no objection to the assumption that, though the ground as a whole is one thick conductor, certain strata are more conductive than others; that generally the electric conductivity of the subsoil changes on both sides of a fault; that a certain conducting clay bed, which may represent the main conductor, is deeper on one side than on the other side of the fault plane; and that on top of an anticline a certain conducting salt-water horizon is nearer the surface than on the slopes, et cetera.

Such simple and logical assumptions are fully sufficient to explain geologically the electromagnetic results and to interpret them so that the information obtained will be of great practical value.
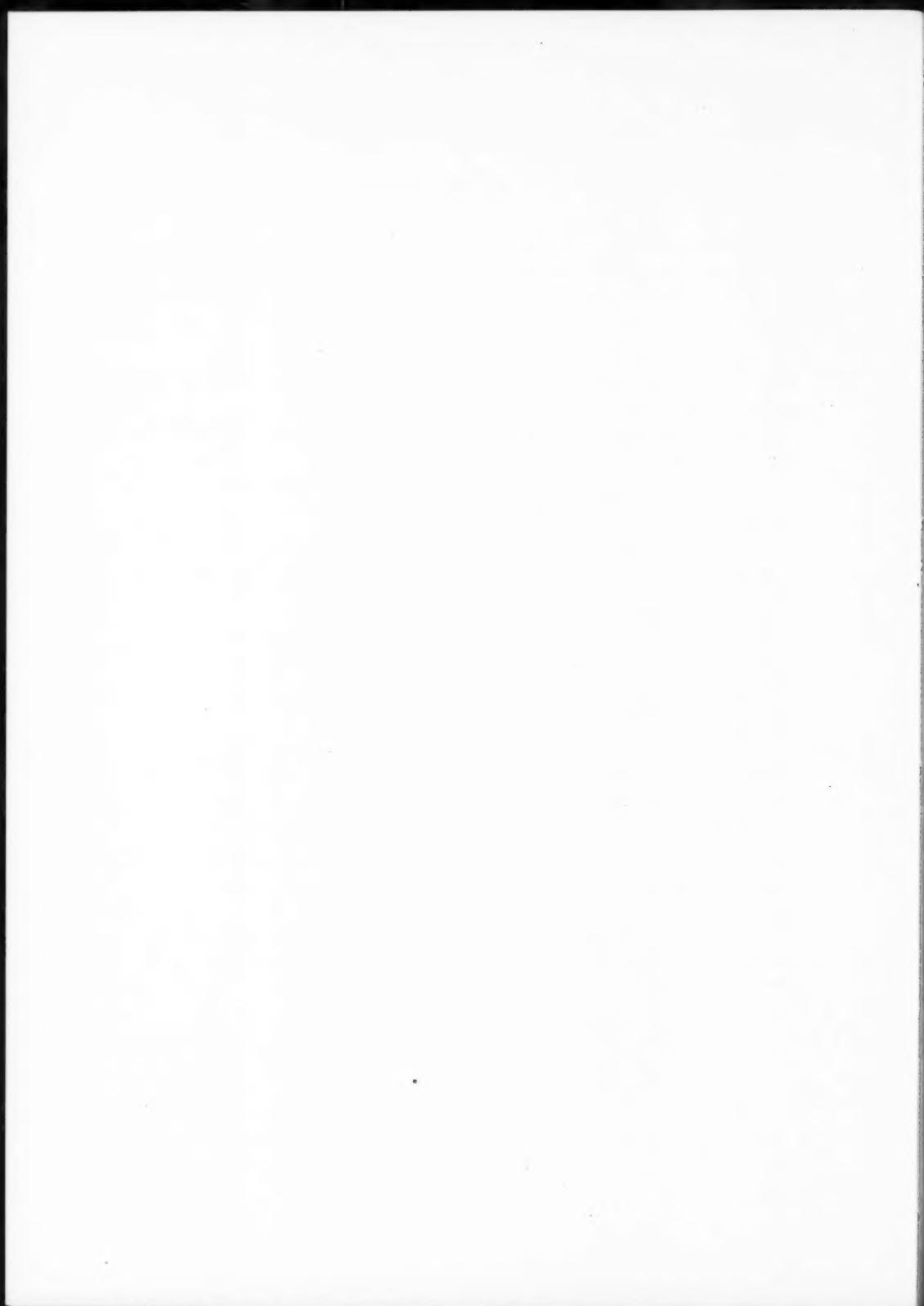
GEOLOGICAL NOTES

ISO-CON MAP FOR ORDOVICIAN WATERS

INTRODUCTION

Concentrations of Ordovician waters differ greatly in the Mid-Continent oil fields, ranging from dilute to almost saturated. In most of the oil fields of Oklahoma they have an average concentration of approximately 160,000 parts per million. In the El Dorado, Kansas, field the average of many analyses is approximately 20,000 parts per million.

The map shown in Figure 1 was prepared to show the distribution of different concentrations, and to determine any geological relationship. The lines on the map, termed iso-cons, connect areas of equal concentrations.

The waters of Missouri, Iowa, and northeastern Kansas are so dilute that an iso-con interval of 1,000 parts per million was used, whereas an interval of 50,000 parts per million was necessary for the very concentrated waters of southern Kansas and Oklahoma.

It will be noticed that an abrupt increase in concentration per unit distance occurs at the 10,000-parts-per-million line.

SOURCES OF INFORMATION

Analyses of Ordovician waters were collected representing as much of the Mid-Continent as possible. About thirty for Iowa were obtained from Norton[1] and others. A few from Missouri were listed by Shepard.[2] Most of the analyses from deep wells in Kansas and Oklahoma were assembled by Ginter from his own files and through the courtesy of the Gypsy Oil Company and the Empire Gas and Fuel Company, to whom the writers are deeply indebted.

GENERAL CHEMICAL CHARACTER OF MID-CONTINENT ORDOVICIAN WATERS

The chemical characteristics of Ordovician waters in the Mid-Continent are, in general, no different from many subsurface waters of other localities and geologic ages.

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[1] W. H. Norton, W. S. Hendrixon, H. E. Simpson, O. E. Meinzer, and others, "Underground Water Resources of Iowa," *U. S. Geol. Survey Water Supply Paper 293* (1912).

[2] E. M. Shepard, "Underground Waters of Missouri," *U. S. Geol. Survey Water Supply Paper 195* (1907).
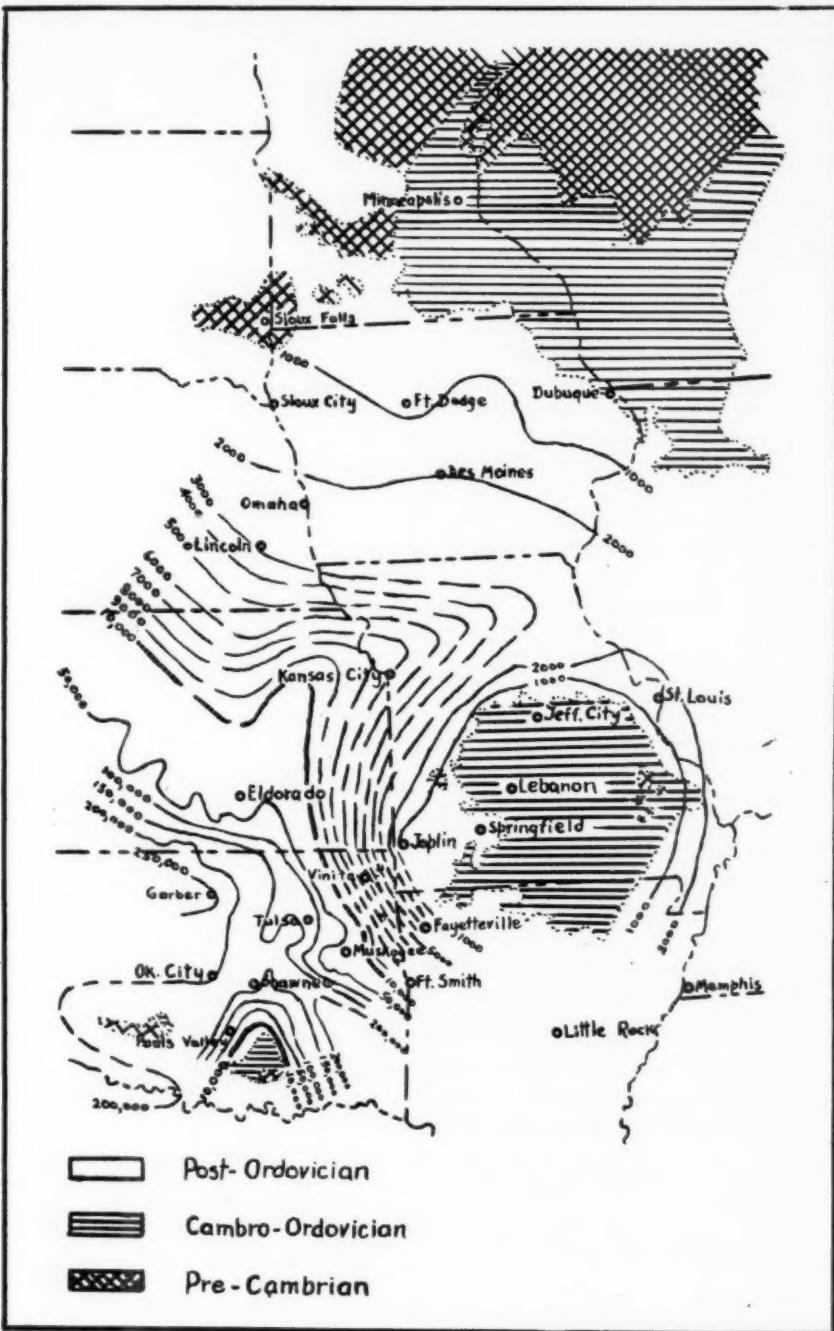
FIG. 1.—Iso-con map for Ordovician waters in Mid-Continent areas of the United States. Lines connect areas of equal concentration, based on parts per million of total solids.

It may be stated that in some of the Oklahoma fields, and in parts of Iowa, there are appreciable differences in concentration and ratios of dissolved constituents in waters from different members of the Ordovician. However, waters from many Oklahoma fields show a uniform character of concentration and composition, throughout the entire Ordovician section.

There does, however, seem to be a relationship between the chemical characteristics of waters in the Ordovician section as a whole, and the outcrops of Ordovician rocks in the Mid-Continent.

A few miles northward and northwestward from the Arbuckle Mountains of Oklahoma, these waters are low in concentration, carry an appreciable amount of bicarbonate alkalinity, and ordinarily contain hydrogen sulphide and a small amount of sulphate. For a much greater distance down the west and southwest flanks of the Ozarks, these same features characterize the subsurface Ordovician water. For a still greater distance southward and southwestward from the Canadian shield, Ordovician waters are found to be very dilute, though of a somewhat different chemical nature.

In contrast to the aforementioned features, the Ordovician waters of the central and east-central section of Oklahoma, northward to the Kansas line, are in the main highly concentrated, exceedingly low in bicarbonate alkalinity, and carry only traces of sulphates, if any. Hydrogen sulphide is not commonly found in the highly concentrated Ordovician waters of the Mid-Continent.

GEOLOGIC FACTORS

The most striking feature of the map is the seeming relationship between the concentration of Ordovician waters and outcrops of Ordovician rocks.

The concentration increases down-dip and seems to increase most rapidly in proximity to the smaller areas of outcrop. In the Arbuckle Mountain area of Oklahoma the concentration increases from 10,000 parts per million to 150,000 parts per million in the distance of 14 miles, or at the rate of 10,000 per mile.

From the Ozarks westward an increase from 1,000 to 150,000 parts per million occurs in a distance of 125 miles, or at the rate of 1,200 per mile. Southwestward from the Canadian shield area in Minnesota and Wisconsin an increase from 300 to 3,000 occurs across the state of Iowa, a distance of 250 miles, and from there to southern Kansas, a distance of 225 miles, the concentration increases to 150,000 parts per

million at an average rate of 315 per mile for the entire distance.   Figure 1 shows the relative size of three areas of outcrops.

CONCLUSIONS

These observations strongly suggest a definite relationship between size of outcrop and concentration.   The rate of increase in concentration down-dip seems to be in inverse ratio to the size of the nearest Ordovician outcrop.

If these features be accepted as facts, the obvious inference is a relationship between meteoric waters, size of Ordovician outcrops, and concentration of subsurface Ordovician waters.

The writers do not offer an explanation as to the mechanism that has brought this dilution about, but simply present the map for what it is worth.

<div align="right">ROBERT H. DOTT[1] and ROY L. GINTER[2]</div>

TULSA, OKLAHOMA
   July 14, 1930

DISCUSSION

L. C. CASE, Tulsa, Oklahoma: It seems a fact that the general relationship of size of outcrop to rate of increase of concentration down-dip does exist. Also, the bending of the iso-cons eastward around the Ozark uplift strongly suggests the influence of comparatively recent infiltration of meteoric water.

Since the existence of these phenomena must be accepted, a question arises as to the physical mechanism bringing about such subsurface conditions. Obviously, water can not enter an outcrop if the formation is already saturated. Or, if water does enter, it forces out water already present. Jointing in adjacent beds may make possible some transverse migration. However, this method seems inadequate to explain dilution at depths of several thousand feet. Russell[3] assumes that the compressibility of sandstone formations is of an elastic nature and that sandstone formations resume, in part, their former volume as overlying sediments are worn away. An examination of this principle is best made by application to the area of dilute water in the "Wilcox" (Ordovician) sand surrounding the Arbuckle Mountains. It might be possible to arrive at average figures, for the purpose of illustration, for such factors as porosity of the "Wilcox" sand, removal of overburden, thickness, et cetera. To compute a possible amount of pore space, created since deposition, and the influx of a specified amount of water in this manner entails much calculation with assumed values. No such calculation is necessary to illustrate the prin-

[1]Sunray Oil Company.

[2]Ginter Chemical Laboratory.

[3]W. L. Russell, "The Origin of Artesian Pressure," *Econ. Geol.*, Vol. 23, No. 2 (1927), pp. 132-57.

ciple. Let us assume a rebound of 0.2 of 1 per cent. It seems that the maximum could not be much in excess of this figure. With this assumption, if the "Wilcox" sand were of constant thickness, 100 miles of the sand would have to have its porosity increased 0.2 of 1 per cent to allow water to fill 0.2 of 1 linear mile of the formation. This, of course, would apply throughout a specified width. It is shown on the iso-con map that the area affected by dilution extends probably more than 15 miles north of the Arbuckle Mountains. Also it is shown on this map that approximately 100 miles north of this outcrop the Ordovician rocks begin to get their dilution from the Ozarks. It is probable that the amount of area affected relative to the area of outcrop is so large that the possibilities of dilution due to this factor are much greater. However, I believe that the factor of elasticity alone is insufficient to account for all the dilution known to have taken place. Thus, while several known causes may have contributed to the process of dilution, it seems that the major physical factor remains to be discovered.

DISCUSSION

ADJUSTMENT OF GRADIENT OF TORSION BALANCE AND APPLICATION OF UNDULATION METHOD TO GRAVITY MEASUREMENTS

Donald C. Barton has given an exact, very good control and adjustment of surveys made with magnetometer or with torsion balance,[1] based on the least-square method and especially fitted for scalars or for vectors of only one direction.

For the gradient vector observed with the torsion balance, the following not very accurate but easy method can be used for two problems, if the inhomogeneities[2] of terrains and the errors of the instrument vary irregularly from station to station, disturbing the results.

1. To find the isogams: a set of n neighboring stations is tied together by the vector polygon (Figs. 1-3, b) and the resulting vector is divided by the number (n) of the stations, giving the average gradient in the center of the set. The number (n) must equal 3 at least; but if the irregularities are very large and the structure not too complicated, a set of more stations ($n = 4$-6) ought to be used. The center of the set can be found by the method given in Figures 1-3,a. The center of gravity of the n equal masses (the stations) must be determined, which can be done by using a graphical method (for three points see Figure 1, a; for four, see Figure 2, a; for five, see Figure 3, a).

2. The regional trend of the gradient shall be found so that it can be subtracted from the local values. For this purpose the same method as previously mentioned, the vector polygon, can be used, whereby the average gradient is found. If the stations are distributed approximately equally in the section, the center of the rectangular section is found as the point of intersection of two diagonals.

The whole region measured can in some areas be divided into 4, 5, or 8 equal rectangular sections, and for each section the average gradient can be determined. In which manner the combination of the different 4, 5, or 8 average gradients can be made depends on the tectonics.

On page 20 of another paper[3] Barton gives triangular cross sections of a series of prisms, all of which produce the same gradient- and differential curva-

[1] Donald C. Barton, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 9 (September, 1929), pp. 1163-86.

[2] It seems to the writer that it would be useful to know before beginning the observations the inhomogeneity of the terrain in the center of the region, by measuring the gradient at the three corners of each of two equilateral triangles, one of which has sides of 15 meters each, and the other of 50 meters each.

[3] Donald C. Barton, "Calculations in the Interpretation of Observations with the Eötvös Torsion Balance," *Geophysical Prospecting, 1929* (Amer. Inst. Min. Met. Eng., New York, 1929), pp. 480-504.

FIGS. 1, 2, and 3

Fig. 4

surface

a ————————————————— e vertical section

Fig. 5

b'

Horizontal section
surface

a'
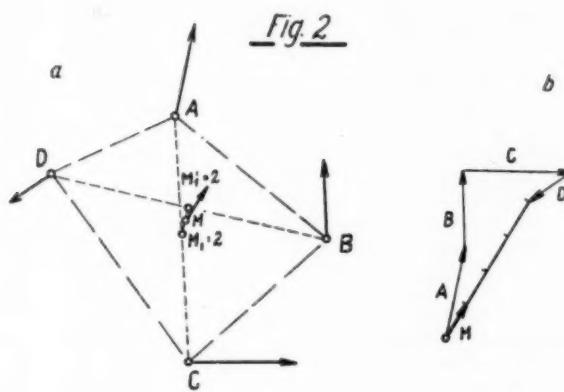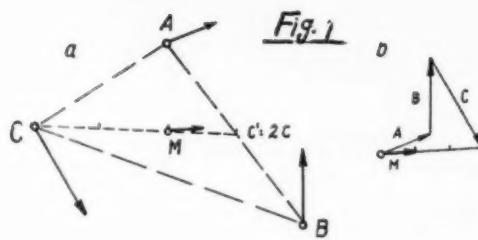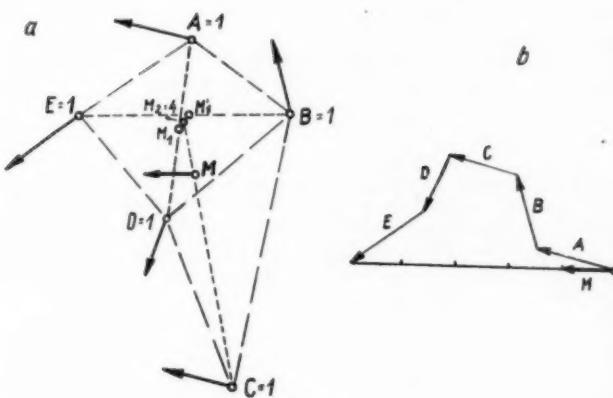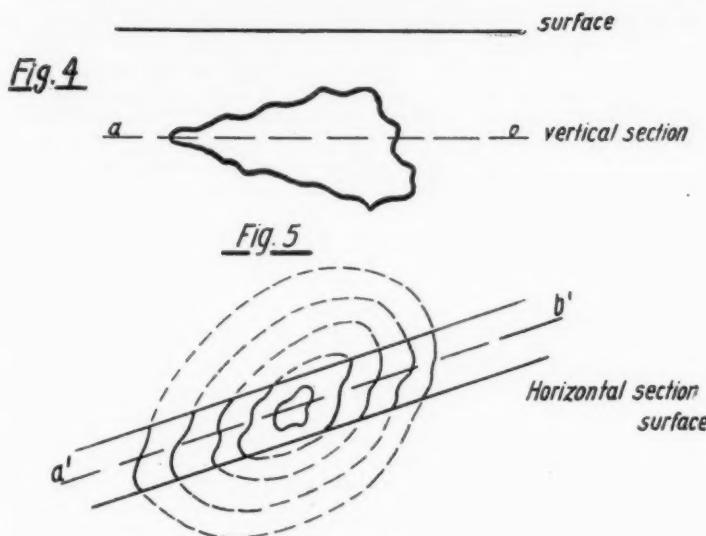
FIGS. 4 and 5

ture-profile within the limits of error, leaving a certain specific gravity differ-
ence against the surrounding medium for each block. The question arises,
whether it would not be possible to distinguish between these forms.[1]

The undulation method[2] can easily distinguish between the different forms.
In nature scarcely a body in the earth would have a wholly regular contour
surface—plane, spherical, or ellipsoidal. The surface would have holes,
excrescences, crevices, channels, or disturbances of some kind (Fig. 4).

Therefore, the isogams can not have a regular shape, but must show irreg-
ularities, that is, undulations (Fig. 5). The least size or extension of these un-
dulations is regular and independent of the dimensions of the small irregular-
ities in the surface of the body. Their size gives the depth and is the same for
the same depth, provided that the dimensions of the irregularities are approx-
imately less than $1/5$ - $1/10$ of the depth. In the flat triangular prism all the
smallest undulations will have a small extension; in the steep, deep triangular

[1]That could theoretically also be made by measuring $\frac{\partial g}{\partial z}$. The regional anomalies

of $\frac{\partial g}{\partial z}$ might be large and not easy to separate from the local anomaly; therefore, the

construction of a field instrument for this scope was delayed.

[2]This method was first proposed by the writer for magnetic measurements and
applied on the magnetic anomaly of Kursk (Russia).

prism, the undulations on the outside will have smaller amplitudes and a large extension. The amplitude can vary, but not the extension.

In the practical application of the method, difficulties can arise caused by inhomogeneities near the surface of the earth; it might even be necessary to make a tabulation of the extensions of the undulations. It would be useful to observe undulations in three different directions; but in practice for determining the location of a bore hole, it is sufficient to make observations on some undulations in the center.

<div align="right">J. G. KOENIGSBERGER</div>

FREIBERG, i. BR.
July, 1930

"ANCESTRAL ROCKY MOUNTAINS" AND SIOUIS

In 1910, in his *Paleogeography of North America*, the writer pictured on his Plate 49 a positive land mass in the eastern Cordilleran region that he called *Siouxia* and defined as "an extensive Paleozoic land embracing the greater part of the Great Plains area of the United States." This same land is again shown (as *Siouis*) on page 139 of the second edition of the Pirsson-Schuchert *Text-book of Geology*, Part II. This positive area is pictured in Figure 1 and now takes on a more definite character and an added structure due to a recent paper by Ver Wiebe entitled "Ancestral Rocky Mountains."[1] With this paper are three maps showing the seaways with their bounding lands and islands in Mississippian, Pennsylvanian, and Permian times, on which are also cited the thickness and nature of the best known exposures. These maps are of great service to all geologists, as are the author's descriptions of the various positive elements of Siouis.

The writer has compared Ver Wiebe's results with his own manuscript maps showing the detailed paleogeography of North America, and out of this comparison has come an altogether better idea of the structural relations of Siouis, which embraces the areas now called the Colorado Plateau, the southern Rockies, and the southern Great Plains. With the Laramide revolution these lands took on a north-south alignment, but in the late Paleozoic, parts of Siouis trended either east-west (Uinta Mountains) or more generally northwest-southeast, turning in eastern Colorado to north-south (Ancestral Rockies), while the south shore extends southwest and northeast. In the Sonora-Ouachita geosyncline south of Siouis, the Paleozoic formations were folded in Pennsylvanian time, with a general trending from southwest to northeast (best seen in Texas), although over great parts of southern Siouis the strata are nearly horizontal and the northwest-southeast or north-south strike structure (central Colorado) seems to be due entirely to sharply elevated elongate fault blocks. This ridged and faulted nature of Siouis is much in evidence in late Paleozoic time, but there is also some evidence for similar movements at the close of the Ordovician, and, in the Grand Canyon region, as far back as pre-Cambrian time.

[1] *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), pp. 765-88.
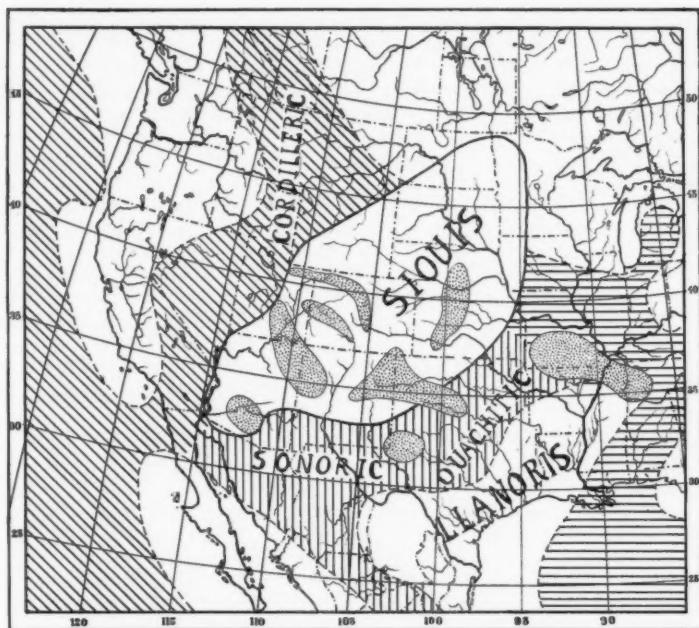
FIG. 1.—Paleogeographic map to show full extent of buried Siouis in Paleozoic time, bounded on west by Cordilleran syncline and on south by Sonora-Ouachita trough. On east, interior seas also invade Siouis and on north various floods from Arctic Ocean. Finally, in Pennsylvanian-Permian time the whole of Siouis is submerged except areas shown dotted.

Central Colorado is the area of Lee's Ancestral Rockies (1918), with north-south strike, which were elevated in late Pennsylvanian time, followed by erosion which furnished "red sediment to the neighboring lowlands and seas."[1] In a later paper (1923) Lee says the Ancestral Rockies were "comparable in size to the present Rocky Mountains, occupied the site of the Southern Rockies, and sediments were shed from them in all directions."[2] Throughout the southern Rockies "overthrust faults are rare and normal faults are numerous." Foldings are rare, hogbacks are common, and the deformation is one of "warping rather than . . . . folding under lateral compression."[3]

[1] Willis T. Lee, "Early Mesozoic Physiography of the Southern Rocky Mountains," *Smiths. Misc. Coll.*, Vol. 69, No. 4 (1918), pp. 1-41.

[2] Willis T. Lee, "Building of the Southern Rocky Mountains," *Bull. Geol. Soc. Amer.*, Vol. 34 (1923), p. 288.

[3] *Op. cit.*, p. 289.

At the foot of the mountains the sedimentary formations "are either sharply upturned or broken off at nearly vertical fault planes."[1] In other words, Lee holds that the southern Rockies were formed by vertical uplift and not through folding. After middle Permian time Siouis was eroded to sea-level, and completely flooded by the Coloradoan sea during late Jurassic and Upper Cretaceous times. Finally, "at the close of the Cretaceous period the deeply buried base of the Ancestral Rockies was raised and highlands reappeared where the sea had been."[2]

Melton, who has also written on the Ancestral Rockies of southern Colorado and New Mexico (1925), calls them the San Luis Mountains, and includes in them the Front Range of Colorado. The present writer would extend this term to all the mountains of Colorado and adjacent states made in Permo-Carboniferous time. The term Ancestral Rockies for Paleozoic mountains of Siouis is misleading, but is more useful applied to the Laramide orogeny, the ancestral mountains of the present Rockies. The San Luis Mountains, Melton says, "are believed to have reached their maximum development in Permian time," the orogeny having started "at least during the latter part of Pennsylvanian time."[3]

Ver Wiebe holds that Siouis probably began its history in Proterozoic time, and this is proved by the late Cambrian paleogeography. The San Luis Mountains may have begun to rise late in Ordovician time, but far more certainly at the close of Mississippian time, as is demonstrated by the very thick and coarse deposits of the Pennsylvanian system. "The Ancestral Rockies of Lee, however, began their history in middle Pennsylvanian time..... The following tectonic elements were the framework of the Ancestral Rockies: Uinta-Front Range element; Uncompahgre-Sangre de Cristo element; Defiance-Zuñi element; Pedernal-Mesa de Maya element; and Amarillo-Wichita element."[4] All of these positive elements he thinks came into existence during, or even before, Proterozoic time. The Uinta element east of Salt Lake City continues into western Colorado with a west-east strike. The Front Range element of Colorado has a north-south strike, and the Sangre de Cristo farther south has the same, but bends toward the southwest and extends to central New Mexico. In the Uncompahgre and Zuñi elements the strike of the Algonkian rocks is northwest-southeast.

Accordingly, Siouis is an ancient positive mass that got its rock structure with west-east or northwest-southeast strikes in the Proterozoic, and in Paleozoic time was bounded on the west by the Cordilleran geosyncline and on the south by the Sonora-Ouachita trough, overlapped on the east by the interior epeiric seas and on the north by rare invasions from the Arctic Ocean (Fig. 1). After the late Cambrian and until late Devonian time, Siouis was rarely invaded by marine floods. These became greater in succeeding time and the old land was most widely covered in the Pennsylvanian and again in the early Permian

[1] *Op. cit.*, p. 290.

[2] *Op. cit.*, p. 288.

[3] F. A. Melton, "The Ancestral Rocky Mountains of Colorado and New Mexico," *Jour. Geol.*, Vol. 33 (1925), pp. 84-90.

[4] Walter A. ver Wiebe, *op. cit.*, p. 765.

period. Later its former dimensions again came into existence, but with the Upper Jurassic and again with the Upper Cretaceous it was completely flooded by inland seas. Siouis may have been block-faulted at the close of the Ordovician, but was certainly widely so faulted at the close of the Mississippian, and again in late Pennsylvanian and early Permian time, when the elongate fault blocks of its western part trended generally northwest-southeast, and, in the east, north-south, finally bending toward the southwest. The younger Laramide north-south fold and thrust structures cross these older trend lines almost at right angles. Some of these statements are visualized on the paleogeographic map (Fig. 1).

CHARLES SCHUCHERT

NEW HAVEN, CONNECTICUT
    July 14, 1930

CHAZY-SYLVAN UNCONFORMITY AT BIG LAKE, TEXAS

In my article on the "Pre-Pennsylvanian Stratigraphy of Big Lake Oil Field, Reagan County, Texas," I stated that "One important angular unconformity is found at Big Lake that has not been noticed in Oklahoma. This occurs between the Sylvan shale (Richmond) and subjacent Ordovician strata of Chazy age."[1]

Mrs. Edson took exception to this and listed the following well known unconformities that occur in Oklahoma.[2]

> Post-Fernvale-pre-Sylvan (intra-Richmond)
> Post-Viola-pre-Fernvale (post-Cincinnatian-pre-Richmond)
> Post-Bromide-pre-Viola (post-Black River-pre-Trenton ?—Cincinnatian)
> Post-Tulip Creek-pre-Bromide (post-Chazy-pre-Black River)

These occur between formations that lie in the interval between the Chazy and the Sylvan, but they are not Chazy-Sylvan unconformities, and they are not correlated with the unconformity at Big Lake. I do not know of any locality in Oklahoma where the Sylvan shale is in contact with the Chazy without faulting.

SHEPARD W. LOWMAN

TULSA, OKLAHOMA
    August 8, 1930

EXCHANGE OF TIME FOR TEMPERATURE IN PETROLEUM GENERATION

Inasmuch as many petroleum geologists do not seem to be acquainted with the experiments of C. G. Maier and Stuart R. Zimmerley relating to the

[1] S. W. Lowman, "Pre-Pennsylvanian Stratigraphy of Big Lake Oil Field, Reagan County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), p. 799.

[2] Fanny Carter Edson, "Lower Paleozoic Unconformities," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 7 (July, 1930), p. 947.

value of geologic time as against heat in the conversion of the organic matter in the sediment, and because of the fundamental bearing of their work on the genesis of oil from buried organic débris in accordance with the "geologic" theory of the origin of petroleum, I venture to summarize in the *Bulletin* some of the outstanding conclusions published by these authors[1] about 6 years ago.

Tests were made on Green River shale from Soldier Summit, Utah, yielding about 40 gallons to the ton by distillation. Samples of the crushed shale were heated in pyrex tubes at different temperatures and throughout different periods. Samples were ground to −60-mesh and air dried at 105° C. When heated rapidly the temperature of first oil formation was found to begin at 365° C., which, therefore, was the upper limit of temperature used in the tests.

Tests made in tubes with perforated stoppers gave variable and confused results and were discarded as of little value or misleading. Thereafter pyrex tubes, 15 centimeters long and with a bore of 2 centimeters, containing 15 grams of finely ground shale, were evacuated and sealed before they were heated for different periods, ranging from a few hours to 144 hours, at 265°, 325°, 300°, and 275° C. Many of the tubes exploded; the pressures generated were very low, though they were estimated to have been as high as, or higher in some experiments than, 15 atmospheres (220 pounds per square inch). After being heated, the shale was extracted in a Soxhlet extractor, carbon tetrachloride being used as a solvent, the solvent evaporated, and the extracted "bitumen" weighed.

The curves showing the amount of organic matter transformed at the end of the various intervals have the appearance of a logarithmic curve. The work shows that "the bitumen formation is a function of the temperature and time of heating," and that the amount "that can ultimately be formed does not depend on the temperature, but that the same amount can be obtained provided that the time of heating is sufficiently long." The rate of conversion is slower at lower temperatures, the change at 275° C. being too slow to make the experiment feasible.

From the analysis of the data derived from the experiments, the authors deduce a formula by which the amount of bitumens to be formed at the end of any period at a fixed temperature can be calculated. Thus the time required for 1 per cent conversion at 100° C. would be 8.4×10^5 in years. This conclusion, though highly stimulating to the geologist, is to an extent qualitative and approximate; neither the organic compounds in the rock nor their molecular weights are known. Further, the formula is based on a single type and rank of shale.

Other conclusions reached are "that the formation of bitumen *per se* is an endothermic process," and "that since the reaction of formation apparently is of the first order, there is no tendency for the bitumen to revert. This is in itself strong evidence for the belief that the bitumen is fundamentally a different substance from the original organic material and that the oil shales are not, as has been supposed by some, argillaceous or shaly material containing absorbed hydrocarbons."

[1]"The Chemical Dynamics of the Transformation of the Organic Matter to Bitumen in Oil Shale," *Bull. Univ. Utah*, Vol. 14, No. 7 (1924), pp. 62-81.

The work described was carried on in the Department of Metallurgical Research of the Engineering Experiment Station of the State School of Mines in coöperation with the U. S. Bureau of Mines, and the Bulletin may be obtained gratis on application to the University of Utah.

DAVID WHITE

WASHINGTON, D. C.
    July, 1930
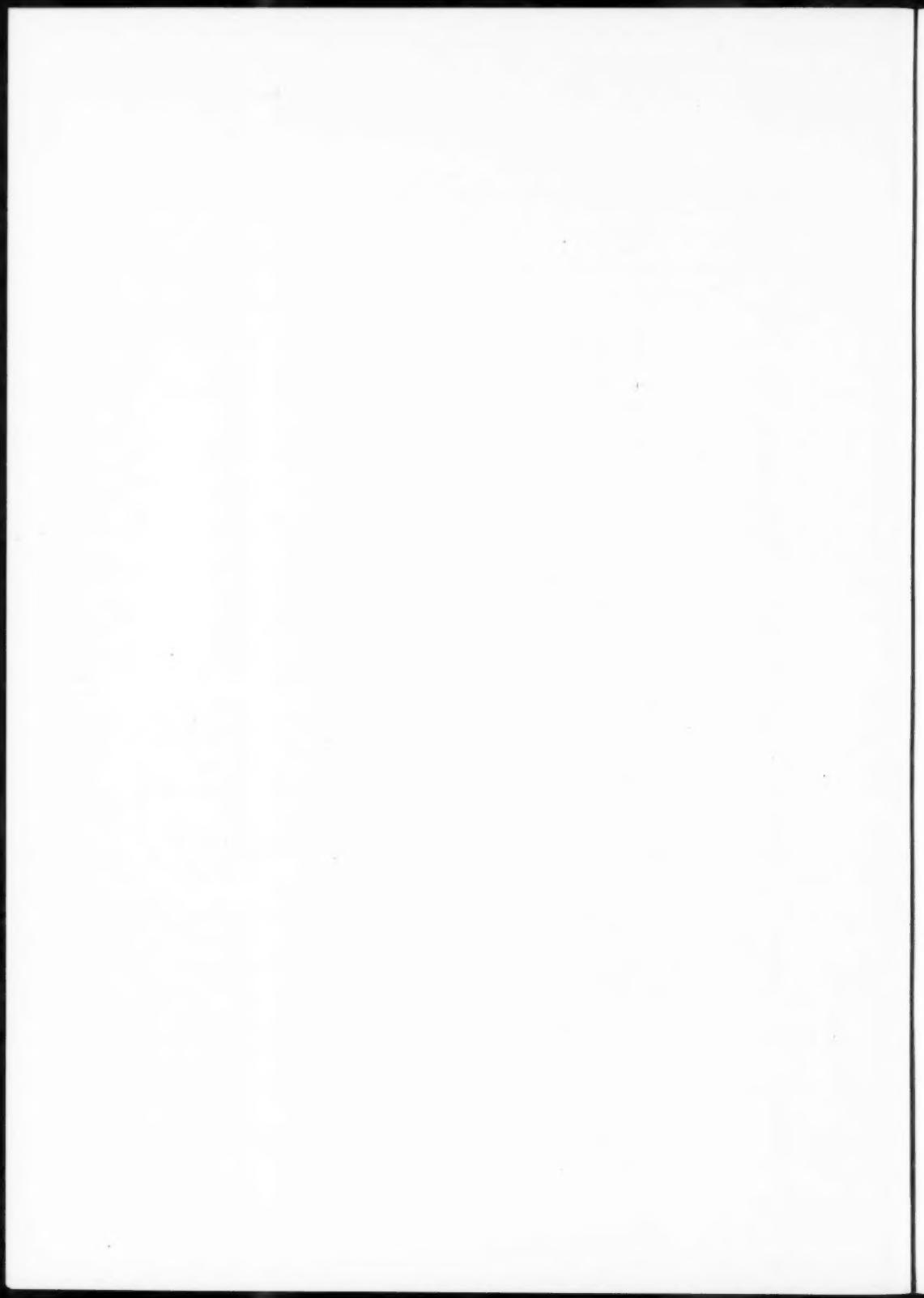
REVIEWS AND NEW PUBLICATIONS .

The Structure of Asia. Edited by J. W. GREGORY, of the University of Glasgow (Methuen and Company, Ltd., London, 1929). 5 × 8 inches. 227 pp. Price, 15 s. net.

This collection of papers was secured by Professor Gregory for the meeting of the British Association for the Advancement of Science held in Glasgow in September, 1928. Separate chapters are as follows: Introduction, by Professor Gregory, 34 pp.; The European Altaids and their Correlation to the Asiatic Structure, by Professor F. E. Suess, of Vienna, 23 pp.; Contribution to the Stratigraphy and Tectonics of the Iranian Ranges, by H. de Böckh, G. M. Lees, and F. D. S. Richardson, of the Anglo-Persian Oil Company, Ltd., 119 pp.; The Tectonic Features of the East Ferghani-Alai Range, by D. I. Mushketov, Director, Geological Commission, U. S. S. R., Leningrad, 9 pp.; Recent Work of the Geological Survey of India on the North-West Himalaya, by W. D. West, Geological Survey of India, 2 pp.; The Structural Evolution of Eastern Asia, by George B. Barbour, Peking, 18 pp.; The Importance of Horizontal Movements in the East Indian Islands, by H. A. Brouwer, University of Delft, 2 pp.

Petroleum geologists are afforded an opportunity to learn about the regional geology of Persia; of details, hitherto unpublished, regarding the remarkable salt domes with salt glaciers in islands of the Persian Gulf and on the mainland; and a bit about the geology of Guatemala, Colombia, and Venezuela, with columnar and cross sections. These data were published with the permission of the Anglo-Persian Oil Company, Ltd.

The tectonic map of Persia shows the location of sixty-three salt domes, many of which are described in the text. Cambrian fossils have been found in the rocks intruded with the salt core in several salt domes. Igneous rocks within the sedimentary column have been cut by several salt cores. The following quotation gives some of the salient facts.

1. Rock salt is capable of flowing like ice. It may be pressed upward along lines of weakness and form accumulations.
The salt domes of Persia give, perhaps, the most perfect exposure and clearest evidence of this behavior of the salt. We shall describe two of the most spectacular examples of the flowing of salt, and show how even great salt glaciers may be formed.
Kuh-i-Angura salt-plug has burst through the highest crest of a long anticline [Fig. 1]. Erosion has exposed Cretaceous rocks in the core of this fold, and massive Eocene limestones form an elliptical amphitheatre. The salt appears to have been squeezed out of a central vent in the Cretaceous limestone, and when a great mass of salt had accumulated it began to flow downhill, like an ice glacier. It has almost completely overridden and enveloped the Eocene limestone scarp on the southern flank of the fold, with the exception of two peaks which still protrude through the salt mass. The sketch shows clearly how the flow of the salt was diverted by topographical obstacles and how it finally reached the alluvial plain.
2. In some cases an accumulation of salt may take place and yet not reach the surface, retaining a cover of overlying sediments. Under certain circumstances, if the
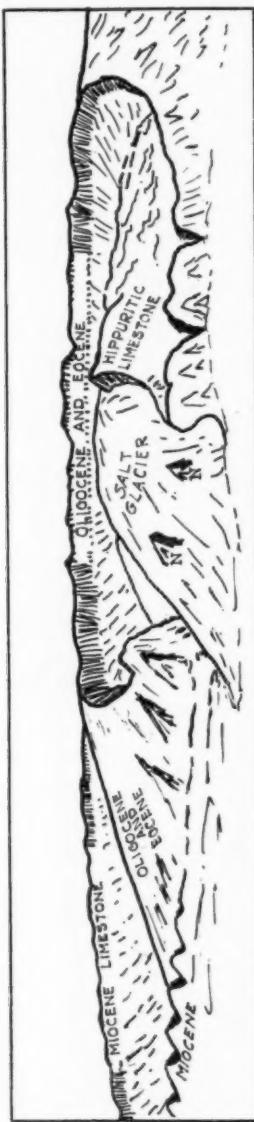
FIG. 1.—Kuh-i-Angura salt dome and salt glacier. It is located on the Persian mainland, north of the east end of Qishm Island at the entrance to the Persian Gulf. Two nunataks (N) of limestone project through the salt glacier. (Redrawn from Plate III.)

movement of salt has ceased, ground water may leach out the salt to a certain level, forming an even surface, the so-called "Salzspiegel" of German authors. The cover of the salt being unsupported will then collapse and break in, forming a chaotic jumble of rocks above the salt-plug.

In other cases, the salt may reach the surface.... the leaching-out and erosion may result in the characteristic negative topographic form, the "Salztrichter."

3. The movements of the salt and its migration from its original position of deposition toward points of weakness are slow and steady processes, though not necessarily continuous. The uprise is governed by local conditions and therefore may take place at different periods in different localities. Many of the Persian Gulf salt-plugs afford clear evidence of the age of the movement of the salt by the development of conglomerates of various ages in their vicinity.

The salt-plugs are generally more or less oval in horizontal section, owing to the fact that this form demands the minimum force to burst through the covering rocks, which may be already slightly arched.

In some cases the salt and rocks of the salt series are intrusive in faulted zones.

Another detail is worth transcription because it relates to the age of folding of the oil-bearing anticlines, Maidan-i-Sulaiman (formerly referred to as Maidan-i-Naftun) and Naft Khaneh. The question has been raised whether the anticlines were initiated after the deposition of the oil-bearing Asmari limestone, of Lower Miocene age. De Böckh and his colleagues write:

We have to admit that epeirogenetic movements, causing the slow folding of major anticlines and synclines, may also play a part in the squeezing out of the Lower Fars (overlying the Asmari), but.... the squeezing out of the Lower Fars has no connection with orogenic movements and might be classified amongst the synepeirogenetic movements. [Illustrations of this type of flowage were reproduced in this *Bulletin*, Vol. 13, No. 6 (June, 1929), pp. 686-87.] In Masjid-i-Sulaiman it can be proved that the higher stages (of the Lower Fars) overlap towards certain parts of the anticline.

In discussing continental drift, de Böckh describes the geology of Guatemala, Colombia, and Venezuela. He reports graptolite-bearing shales of Ordovician age from the Cordillera Central, near Puerto Berrio, Colombia. He also mentions the presence of salt domes about 40 miles north of Bogota.

This volume is a very stimulating treatise on tectonic geology and is recommended to all interested in the broader phases of structural geology.

SIDNEY POWERS

TULSA, OKLAHOMA
July 15, 1930

Deposition of the Sedimentary Rocks. By J. E. MARR (Cambridge University Press, 1929; The Macmillan Company, New York). 5 × 7½ inches. 245 pp. Price, $2.40 (7s. 6d.).

The author has given, in a very interesting manner, an account of the main features of the sedimentary deposits which remain, with minor changes, as they were found. The effects of pressure, cementation, and crystallization are considered of minor importance, but he points out that rocks can change their characteristics as a result of these changes.

Uses of lithology and fossils and their importance to the geologist in determining ages of formations are described. The importance of a study of

deposits of land masses and of a comparison of these with marine formations now being formed is stressed.

Marine deposits are divided into belts of sedimentation: an inner belt adjoining the coast is called the belt of variables; farther out, where conditions are more uniform, is the mud belt; and outside the outer side of the mud line is the organic belt where the main organic deposits are found. Cycles and epicycles of deposition are discussed, showing clearly the reasons for differences in deposits. Except for differences in detail, conditions are shown to be much the same throughout wide areas, and sediments are much the same in lithology and organic content throughout the world, but no one small area can be used as a criterion for the rest of the world. Data should be gathered from as many places as possible and the present as well as the past should be drawn on to solve geologic problems.

A study of this book is valuable to both the geographer and the geologist.

DOLLIE RADLER

TULSA, OKLAHOMA
July 17, 1930

Grundfragen der Oelgeologie (Basic Questions of Oil Geology). By KARL KREJCI (Verlag von Ferdinand Enke, Stuttgart, 1930). 182 pp., 7 figs. Price, 20 M.

The author is thoroughly familiar with the conditions in the Roumanian fields and has the advantages and disadvantages of such a position, having had to rely on the literature for information concerning most of the other oil-producing areas.

The first chapter is on nomenclature of sediments, bitumina, bituminous rocks, and water.

In the second chapter, source rocks are defined as dark (ordinarily black) shales (and possibly limestones) containing adsorbed bitumen and pyrites. Calcareous fossils are absent, but horny substance is preserved (fish scales). There are no indications of wave action or other movements during deposition, as these would have destroyed the organic substance before it was transformed into oil. This is the way source rocks look now, after the oil has left them. They have been deposited in places without currents or where the H_2S content of the water does not permit oxidation. Such places are either lagoons or similar shallow waters near the coast in which the sedimentation later changes to salt, or large basins like the Black Sea. The source rock in Roumania is the Cornu formation (upper Oligocene).

Migration (chapter 3) is due to differential pressure (overburden, structural stresses, pressure of liquids and gases) and capillary attraction. Plastic rocks, and still more, liquids and gases, move from areas of higher pressure to areas of lower pressure. These substances move into unfilled pores and cavities, toward the axis of an anticline and toward the surface. Where source bed and present reservoir are separated by impervious strata, the migration is supposed to take place along fissures and crevices ordinarily formed by tectonic movements. Veins of ozokerite and asphalt prove the existence of such

conduits. In upfolded areas of Roumania a thick series of sands separated by shale contains oil, in places even below and above a thrust plane of considerable magnitude, and the author believes that all this oil has migrated upward from the underlying Cornu formation. In view of the extremely complicated structure of the Carpathians, which is not yet fully understood in all details, the author's ideas should be applied to other fields only if they check with all the known facts. Evidence of migration along fissures is not plentiful in other fields. In spite of the evidence in many publications, the author believes that the low dips in the Mid-Continent field do not permit anticlinal accumulation, but thinks it due to physical properties of the reservoir rock. It must be emphasized that most pools in the Mid-Continent are anticlinal and that accumulation in the upper part of sand lenses is only a special case and is in full conformity with the anticlinal theory. Movements along low angles may require more time, and may be too slow for accumulation in young formations.

In chapter 4, on reservoir rocks, it is stated that lime producers are of longer life than wells in sandstone. The opposite is true in the Mid-Continent field.

Chapter 5, on distribution of contents in the reservoir, gives very interesting facts on Roumania. There is no connection between amount of accumulated oil and distance to the adjoining synclines. The production extends farther down on the steeper flank of the anticlines and also along the anticlinal axis. The area of oil accumulation becomes smaller in consecutively higher sands. Paraffine oil becomes lighter closer to the surface, but asphalt oil becomes heavier due to seepage and oxidation. Water analysis can not be used for correlation. These facts tend to support the theory of a common origin of the oil and water of one pool in a common source rock underneath the producing sands. They are local conditions and not general in the oil fields of the world.

In chapter 6, on pressure, we learn that in Roumania the pressure in the reservoir may be higher than the hydrostatic pressure corresponding with the depth.

Chapter 7 deals with the evolution of the contents of the deposit. The author considers the contribution of organic substance from more highly organized animals or plants as negligible. Most of the oil is derived from plankton. As most of these organisms have no skeleton and lime shells are dissolved, there is only slight chance of finding remains of the oil-forming low animals and plants in the source rocks. Protein and fat furnished the bulk of the oil. It is thought to be formed in the early diagenetic stages before the sediment becomes solid, at low temperature and not at great depth. Different grades of oil are partly due to chemical changes (catalyzers), partly to filtration, adsorption of paraffine, or deposition of paraffine on account of gas expansion. Asphaltic oils are due to oxidation near the present or a fossil surface. The author does not favor calling oil-field waters fossil sea water. The main reasons are: difference in chemistry, especially iodine content, of oil-field waters, salt-water content of fresh-water deposits, and lack of water in many water deposits. The author thinks that at a distance from the oil regions the sediments do not contain salt water. The very first stages of consolidation of fresh sediments consist in losing most of the water. The deposited organic matter contains enough water to account for all the oil-field waters. The plankton organisms

contain as much as 99 per cent of water. If any organic matter is oxidized, additional water is formed. This water takes up the chlorides, bromides, and iodides contained in the organic matter, thus forming the present oil-field waters as a by-product of the oil (salt deposits commonly furnish additional $NaCl$). Both oil and water have migrated from the source rock to their present position.

In chapter 8 the evolution of deposits is traced from the formation of the source rock, through migration, into large accumulation, and to the final destruction by erosion.

Chapter 9 deals with geothermic problems.

Chapter 10 contains a few hints for the field geologist and production engineer.

The 11th and final chapter contains tables and remarks on the stratigraphy of various oil regions showing the facies of the oil series. In the United States we find Ohio, Washington County, Utah, Gulf Coast, Navajo country, Sweetgrass Arch, Howard County, North-Central Texas, Bexar County, Texas, Ventura Avenue, and Wyoming. A section from the Oklahoma-Kansas region would not have been out of place. The Roumanian Tertiary section is given in detail. Traces of oil in granite underneath oil sand in the Vienna basin are of interest.

Though the author has not solved all the basic questions of oil geology, he has furnished many valuable observations and his theories are worth testing in all the oil fields of the world. Thus many of these difficult problems will be brought closer to solution.

EDWARD BLOESCH

TULSA, OKLAHOMA
    July 19, 1930

Petroleum Development and Technology, 1930. By the Petroleum Division, American Institute of Mining and Metallurgical Engineers, Inc., 29 West 39th Street, New York, N. Y. (1930). 610 pp., illustrated, cloth. Price, $5.00.

The 1930 volume of the Petroleum Division of the A. I. M. M. E. came off the press in early July. The book contains 610 pages inclusive of index.

The volume contains the papers presented at sessions of the Petroleum Division of the Institute, including meetings at Tulsa and Los Angeles in 1929 and at the annual meeting in New York in February, 1930. Papers are included on unitization, production engineering, research, economics, production review of the producing districts, refining and engineering education.

There are 70 papers and discussions requiring 130 pages on the subject of unit operation, or coöperative development of oil and gas pools. This is the most complete discussion of that interesting subject yet collected. Henry L. Doherty, who is considered the father of the unit operation plan, took an active part in the discussion. As usual, much of the volume is devoted to production engineering and research. Under Production Engineering, there are chapters on Well Spacing, Gas-Oil Ratios, Hydraulics of Flowing Wells, In-

creasing the Extraction of Oil, Valuation Methods, etc., and under Research, chapters on Oil Recovery, Cementing Wells, Drilling Muds, and Corrosion. A chapter is devoted to Petroleum Economics, and Domestic and Foreign Production are each covered in a separate chapter.

Any person engaged in the oil business who desires to keep abreast with new methods, new plans, new discoveries in production methods, and the domestic production statistics of the past calendar year should read this volume and have it available for reference.

JAMES H. GARDNER

TULSA, OKLAHOMA
July 21, 1930

RECENT PUBLICATIONS

AFRICA

"Sind in Südafrika nutzbare Öllagerstätten zu erwarten?" by K. Hummel. *Petrol. Zeits.* (Berlin, August 6, 1930), pp. 835-37.

CALIFORNIA

"What the Drill Reveals of Subsurface Geology at Venice," by Thor Warner. *Petroleum World and Oil Age* (Los Angeles, California, August, 1930), pp. 78-80, 1 illus.

"Presence of the McLure Shale on the West Side of San Joaquin Valley," by Gerard Henny. *Petroleum World and Oil Age* (Los Angeles, California, August, 1930), pp. 97-99, 117, 3 illus.

COLORADO

"The Flora of the Denver and Associated Formations of Colorado," by F. H. Knowlton (a posthumous work, edited by E. W. Berry). *U. S. Geol. Survey Prof. Paper 155* (Supt. Documents, Washington, D. C.).

GENERAL

Sand Movement, Beaches, and Kindred Subjects. A Bibliography, by H. E. Haferkorn, librarian, Engineer School Library, Army War College, D. C. A bibliography with 1,101 items and an index on sand movement and beaches, including references on bars, bays, coast changes, currents, erosion, estuaries, shore lines, tides, waves, and wave actions. A copy of this valuable bibliography can be obtained from the author gratis.

Compte Rendu du IIe Congrès International de Forages (Second International Drilling Congress, Paris, September 16-23, 1929). These proceedings form a work of 718 pages divided into several chapters: (1) organization of the congress, a general list of delegates, program of the congress, entertainments, and excursions; (2) technical papers. The papers, 67 in number, are supplemented by discussions. They include 19 reports on geology and stratigraphy; 10 reports on geophysical methods of prospecting; 18 on drilling technique and related subjects; 5 on drilling application; 13 on economics and statistics of drilling and recording of results; and 2 on drilling laws. Orders taken by the

secretary of the Congress, 85 Boulevard du Montparnasse, Paris (6ᵉ). 2 vols. 718 pp. Price, 100 francs.

"Die Permformation und das Erdöl," by A. F. von Stahl. *Petrol. Zeits.* (Berlin, August 6, 1930), pp. 838-40.

GEOPHYSICS

"Geo-electrical Exploration Methods Used in Oil Fields," by Helmer Hedstrom. *Oil Weekly* (Houston, Texas, July 25, 1930), pp. 34-36, 82, 3 figs.

JAPAN

"Petroleum Resources of Japan Described by Imperial Geologist," by Yoshinosuke Chitani. *Oil and Gas Journal* (Tulsa, Oklahoma, August 14, 1930), pp. 165, 166, 169.

OKLAHOMA

Oil and Gas in Oklahoma. Oklahoma. Geol. Survey Bull. 40 (Norman, Oklahoma). Volume I, general papers; 287 pp.; price, cloth-bound, $1.65. Volume II, western counties; 501 pp.; price, cloth-bound, $3.15. Volume III, eastern counties; 663 pp.; price, cloth-bound, $4.70. Volumes I, II, and III, per set, cloth-bound, $8.85.

TEXAS

"Ground Subsidence at Sour Lake, Texas," by E. H. Sellards. *Min. and Met.* (New York, August, 1930), pp. 377-80, 3 figs.

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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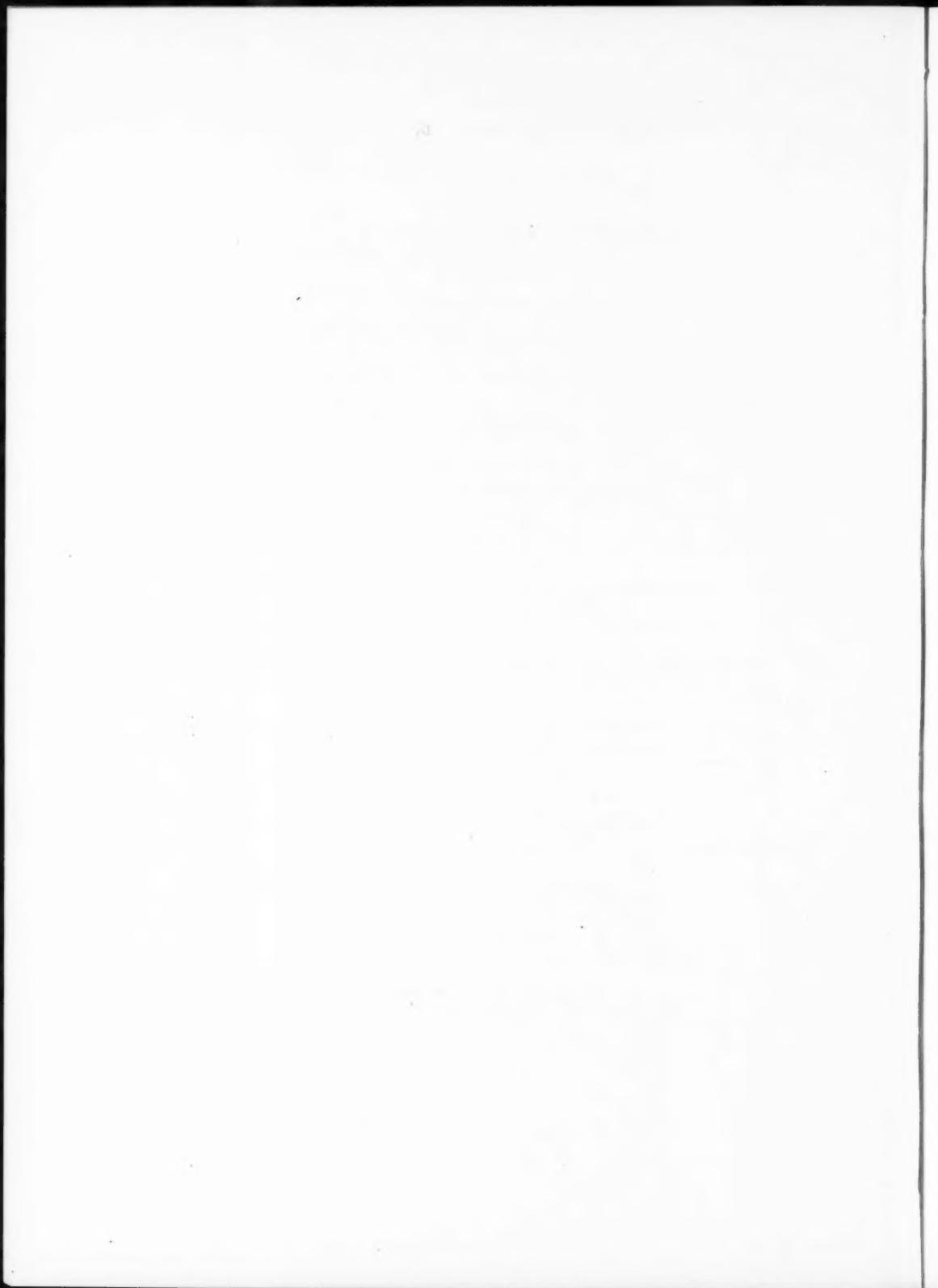
AT HOME AND ABROAD

WANTED—ideas for an Association seal. A committee has been appointed to select and submit to the general business committee sketches for an official Association seal. Suggestions are desired. Please make a sketch or design and send it to R. C. Moore, chairman, Association Seal Committee, University of Kansas, Lawrence, Kansas.

EMPLOYMENT

The Association maintains an employment service at headquarters under the supervision of J. P. D. Hull, business manager.

This service is available to members who desire new positions and to companies and others who desire Association members as employees. All requests and information are handled confidentially and gratuitously.

To make this service of maximum value it is essential that members coöperate fully with Mr. Hull, especially concerning positions available to active and associate members.

D. M. CASHIN, chief geologist for the Navarro Oil Company, Houston, Texas, has resigned to become chief geologist for the Warner-Quinlan Company, with offices in Dallas.

HARRY H. POWER has been appointed chief engineer of the Gypsy Oil Company, Tulsa, Oklahoma, to succeed R. L. WRIGHT, who has resigned.

THOMAS S. HARRISON has recently moved from Denver, Colorado, to California. His new address is Box 324, Encinitas, California.

HOWARD C. WARREN has resigned from the Empire Companies and has formed the firm of Warren and Boykin, consulting geophysicists, Box 1311, Houston, Texas.

W. P. JENNY has recently accepted a position as geophysicist for the Magnolia Petroleum Company, Dallas, Texas.

GEORGE W. SNIDER is employed in the geology and land department of the Darby Petroleum Corporation, 1514 Milam Building, San Antonio, Texas.

DILWORTH S. HAGER has moved his office from Dallas, Texas, to 515-516 Milam Building, San Antonio, Texas.

GRADY KIRBY is in charge of geological work in the Gulf Coast district and in southwest Texas for the Sinclair Oil and Gas Company. His address is 914 Esperson Building, Houston, Texas.

J. S. ROSS, 2012 Hemphill Street, Fort Worth, Texas, has an article on "Cotton Valley Deep Sand Development" in the July 24 issue of the *Oil and Gas Journal*.

DONUIL HILLIS, formerly of 728 South New Hampshire Avenue, Los Angeles, California, is now geologist for the Robert Oil Corporation, Breckenridge, Texas.

W. TAYLOR THOM, JR., and RICHARD M. FIELD, of Princeton University, Princeton, New Jersey, have a brief article on "The Advancement of Geology Through Coöperative Research" in the August 1 issue of *Science*.

A. N. MURRAY, of the department of geology, University of Tulsa, Tulsa, Oklahoma, has an article on "Limestone Oil Reservoirs of the Northeastern United States and of Ontario, Canada," in the August issue of *Economic Geology*.

G. C. POTTER has resigned as chief geologist for the McMan Oil and Gas Company, Tulsa, to engage in independent geological consulting work. His offices will be at 625 McBirney Building, Tulsa, in care of the Exchange Drilling Company.

LEWIS W. MACNAUGHTON resigned as geologist for the Rycade Oil Corporation, effective July 1, to become district geologist for the Amerada Petroleum Company in charge of their east and southwest Texas district. Mr. MacNaughton's headquarters will be 1718 Milam Building, San Antonio, Texas.

GEORGE M. BEVIER, 2106 Truxillo Street, Houston, Texas, has resigned as chief geologist for The Pure Oil Company in the Gulf Coast district, and will engage in consulting practice with headquarters at Houston. He will carry on geological investigations as before, together with seismograph interpretative work.

GEORGE OTIS SMITH, director of the U. S. Geological Survey, Washington, D. C., has an article on "The Engineer's Larger Opportunity" in the August issue of *Mining and Metallurgy*.

H. FOSTER BAIN, secretary of the American Institute of Mining and Metallurgical Engineers, has an article on "Minerals in a Power-Controlled World" in the August issue of *Mining and Metallurgy*. This article is an excerpt from an address delivered before the World Power Conference, Berlin, June 17, 1930.

MARCEL E. TOUWAIDE, for the last two and a half years a petroleum engineer for the Royal Dutch group in Borneo, is now prospecting for oil in French Morocco. His address is: Souk el Arba du Gharb, Morocco.

JAMES B. TEMPLETON, consulting geologist, 2910 West Broadway, Muskogee, Oklahoma, who returned June 1 from San Domingo, has left for several months' work in Europe.

The San Antonio Section of the Association held its August meeting at Corpus Christi, Texas, on Saturday, August 2. The purpose of this meeting was to get together as many as possible of the geologists working in the Corpus Christi area of the San Antonio district, and discuss problems of especial interest in that area. The meeting was attended by approximately one hundred thirty geologists and guests. A dinner was held on the Plaza Hotel "Deck" and was followed by the presentation of the following papers: "The Physiography and Geology of the Beaumont Formation" and "The White Point-Saxet Gas Field" by W. Armstrong Price; "The Agua Dulce Gas Field" by A. E. Getzendaner; "The Mount Lucas Gas Field" by Phillip F. Martyn; "The

Pettus Oil Field" by Bruce Whitcomb; and "The Refugio Field" by George Maddren. The visiting ladies were entertained by the wives of the Corpus Christi geologists at a dinner and a bridge party at the Nueces Hotel from 7:00 to 11:00 P. M. At the conclusion of the technical session and the bridge party many of the geologists and the ladies attended a dance held on "The Ship" in Corpus Christi bay. Arrangements for the meeting were very capably handled by the geologists and their wives located at Corpus Christi, and especial credit for the meeting should go to A. E. Getzendaner, who had supervision of the arrangements.

R. S. McFarland has been elected vice-president of the Sunray Oil Corporation, with headquarters in Tulsa.

James W. Kisling, Jr., of the Amerada Petroleum Corporation, has been transferred from Shreveport, Louisiana, to Roswell, New Mexico.

A. J. Bauernschmidt, Jr., is paleontologist for the Union Sulphur Company at Sulphur, Louisiana.

H. E. Redmon has resigned from Thompson and Black, of Tulsa, to accept a position with the National Refining Company at El Dorado, Kansas.

Cyrus W. Magalis is employed by the Arkansas Fuel Oil Company. His address is 1925 Alamo National Bank Building, San Antonio, Texas.

Robert H. Durward is employed in the geological department of the Big Lake Oil Company at Texon, Texas. Melvin J. Collins is chief geologist and head of this department.

Roderick Burnham, of the Burnham Exploration Company, and until recently manager of lands of the Union Oil Company, Los Angeles, California, is executive vice-president and treasurer of the Central American Aviation Corporation, which recently inaugurated a new air line from Los Angeles to Guatemala, South America.

R. P. McLaughlin, petroleum engineer and geologist, 850 Subway Terminal Building, Los Angeles, California, has an article on "Making Crooked Holes Useful" in the August issue of the *Oil Bulletin*.

J. E. Elliott, president of the Elliott Core Drilling Company at Los Angeles, and Ruth Plummer Terry, of Portland, Oregon, were married July 23 at the Biltmore Hotel, Los Angeles, California.

J. Elmer Thomas, consulting geologist, of Fort Worth, Texas, has an article on "California's Oil Industry Through Texas Eyes" in the August issue of *Oil Bulletin*.

J. J. Zorichak has been appointed petroleum engineer for the Midwest Refining Company, with headquarters at Casper, Wyoming. He succeeds Fred E. Wood, who has resigned to accept a position as petroleum engineer in the production department of the Standard Oil Company of Indiana, 910 S. Michigan Avenue, Chicago, Illinois.

In an item in the July *Bulletin* to the effect that Karl E. Young has organized the Louisiana Paleontological Laboratories, Inc., the address was inadvertently given as Lafayette, Louisiana. The laboratories are located at Baldwin, and Mr. Young's correct address is Box 218, Baldwin, Louisiana.

J. H. TANDY, formerly with the Dixie Oil Company, has opened a consulting office at 533 Tulsa Trust Building, Tulsa, Oklahoma.

WILLIAM M. HOWARD, of San Antonio, Texas, is now employed by the Gulf Exploration Company, at Batavia, Java, D. E. I.

MARIA SPENCER is employed as a paleontologist by the Superior Oil Company at San Angelo, Texas.

JAMES B. HOOVER is core drill geologist for the Shell Petroleum Corporation at Dallas, Texas.

EUGENE A. STEPHENSON, Pittsburgh, Pennsylvania, has accepted the position of professor of petroleum engineering at the Missouri School of Mines and Metallurgy, Rolla, Missouri.

WESLEY G. GISH, chief geologist for the Sinclair Oil and Gas Company, at Tulsa, Oklahoma, has been made a vice-president and director of the company.

C. C. HOFFMAN, who has been district geologist at Fort Worth, Texas, for the Empire Gas and Fuel Company, has been transferred to Bartlesville, Oklahoma, and has been made chief geologist of the Cities Service Gas Company.

O. STUTZER, director of the Institute for Fuel Geology in Freiberg, Germany, has an article on "Ein Überblick über Südamerikas Ölfelder" in the August 6 issue of *Petroleum Zeitschrift*.

JOSIAH BRIDGE has resigned from the department of geology, Missouri School of Mines and Metallurgy, Rolla, Missouri, to accept a position with the U. S. Geological Survey, Washington, D. C.

W. STORRS COLE, of Cornell University, Ithaca, New York, has an article on "The Interpretation of Intrenched Meanders," in the July-August issue of the *Journal of Geology*.

W. ARMSTRONG PRICE has moved his headquarters to Corpus Christi, Texas, to look after the interests of the Saxet Oil Company and Saxet Gas Company in that area. A consulting office will be maintained in the Esperson Building, Houston. The Corpus Christi addresses are 2021 Van Loan and Box 112.

The annual meeting of the Pacific Section of the Association will be held November 6 and 7 at Los Angeles, California. Place of meeting will be announced later. Part of the technical program will be devoted to a symposium on the origin of oil with particular reference to occurrence and source of oil in California fields. Other papers will include subjects on petroleum geology, petroleum engineering, paleontology and general geology. Such papers will be solicited from Association members and from non-members introduced by members. Subjects and abstracts for the program and time required for delivery should be sent to M. G. Edwards, Shell Petroleum Corporation, 433 Higgins Building, Los Angeles, three weeks in advance of the meeting. The Association has the option to publish all papers presented at this meeting.

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